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PIETRO TACCHINI

By A. RICCÒ

On March 24, 1905, at Spilamberto (Modena), there ended the life of a man to whom Italian astronomy, meteorology and geodynamics are indebted for important progress and great developments.

Pietro Tacchini was born at Modena, on March 21, 1838. In 1857 he carried on studies in theoretical engineering with great success at the university of his native city. In 1858 the ducal government of Modena, influenced by Tacchini's special tastes, sent him to the Observatory of Padua, in order that he might study theoretical and practical astronomy under the direction of Santini and Trettenero. In 1859, when only twenty-one years of age, he was appointed temporary director of the Observatory of Modena, which Bianchi had left on the occasion of the change of government.

In 1863 he obtained the position of assistant astronomer at the Observatory of Palermo, which he had sought in order that he might enjoy better means of research and a more favorable sky than at Modena. At Palermo he devoted himself with great zeal to solar investigations, and initiated the beautiful and important series of direct and spectroscopic observations which he continued nearly thirty years and which gave him a great reputation.

In conjunction with Father Secchi, he founded in 1872 the *Società degli Spettroscopisti Italiani*, which he directed with the most steadfast devotion up to his last days. After the death of Father Secchi, the Italian government having taken possession of the Observatory of the Roman College, Tacchini was appointed its director in 1879, and also director of the Central Meteorological Bureau. He organized both of these institutions with great energy and skill; he established the daily meteorological bulletin, the forecasting and storm service, and the studies for a magnetic chart of Italy. In 1887 a section of geodynamics was added to this bureau. The Copernican Museum, annexed to the observatory, was greatly improved and developed by Tacchini. In 1895 he founded the *Società Sismologica Italiana* and the bulletin of this society.

The marked initiative of Tacchini is also illustrated outside of the institutions which he directed. In 1880 he succeeded in starting, and later in completing, the construction of an observatory on Monte Cimone at an altitude of 2160 meters, and in the same year he obtained the means required for the construction of the observatory on Etna at an altitude of 2950 meters. In 1885 he also secured means to erect an observatory at Catania in connection with the one on Etna; and he furthermore succeeded in causing the establishment of a chair of astrophysics, the only one in Italy, at the University of Catania.

Having persuaded the Italian government to take part in the international photographic catalogue and chart of the heavens, Tacchini proposed that the Observatory of Catania be the Italian station. In 1892 the photographic building was erected and the photographic telescope placed in it.

Tacchini's scientific activity was remarkable. At Palermo, in addition to the daily solar observations, he determined the difference in longitude between Palermo and Naples; observed with the meridian circle 1001 southern stars, which were reduced and catalogued by Father Hagen; and made studies of the climate of Palermo. In 1870 he went to Terranova (Sicily) to observe the total eclipse of the Sun; in 1874, to Muddapur (India) to observe the transit of *Venus*. Then he undertook a series of expeditions to distant countries for the purpose of observing solar eclipses: to Kamorta (Nicobar) in 1875, to Sohag (Egypt) in 1882, to Caroline Island (in the Pacific)

in 1883, to Grenada (Lesser Antilles) in 1886, to Surriscaja (Russia) in 1887, to Menérville (Algiers) in 1900; he also expected to go to Spain to observe the eclipse of August 30 next. On these expeditions he obtained many important results, of which I may mention only the discovery of the *white prominences* of the Sun.

The greater part of the numerous investigations of Tacchini are published in the *Memorie della Società degli Spettroscopisti Italiana*, the *Memorie del R. Osservatorio del Collegio Romano*, the *Atti della R. Accademia dei Lincei*, the *Comptes Rendus*, etc. He directed the editorial work of the *Memorie della Società degli Spettroscopisti Italiana* with the greatest devotion during about thirty years.

In recognition of his merits he was elected to membership in various scientific academies and societies in Italy and abroad, such as the Accademia dei XL, the Accademia reale dei Lincei, and the Royal Society of London, which awarded him the Rumford medal in 1888; the Paris Academy awarded him the Janssen medal in 1892. He was a collaborator of the *Astrophysical Journal*. The Italian government appointed him Commander of the Crown of Italy, and Chevalier of the Order of Merit of Savoy.

After forty years of very active service, he was retired at his own request in 1899, to the great regret of his friends and admirers who saw our country deprived of the work of such a man. But he enjoyed little opportunity for rest in the country and among his relatives. A serious attack of pneumonia, complicated by an affection of the liver, carried him off at the moderate age of sixty-seven years.

Tacchini was the object of much friendship and regard in Italy and abroad because of his frankness and loyalty, his cheerful and amiable character, and his great kindness of heart. The heavy loss experienced by our country and by science will always be deeply deplored.

OSSERVATORIO DI CATANIA
May 5, 1905.

RESEARCHES IN THE SUN-SPOT SPECTRUM, REGION F TO *a*

By WALTER M. MITCHELL

INTRODUCTION

The results embodied in this paper are the outcome of a detailed study of the F--*a* region of the sun-spot spectrum, made at Princeton in the year March 1904–1905.

The purpose of the investigations was to obtain as complete a table of lines as possible in this portion of the sun-spot spectrum, and to secure spectroscopic evidence on which to base a discussion of the various sun-spot theories.

INSTRUMENT AND METHODS

The instrument used was the spectroscope of the Halsted Observatory. The telescope itself is a refractor of 23 inches aperture and 30 feet focal length, made by the Clarks. A stiff frame of four steel rods is carried by two rings which fit over the tailpiece of the telescope.[1] This frame carries the spectroscope. The collimator is mounted centrally in it, in such a way that it can be adjusted with respect to the optical axis of the telescope, and can also be moved longitudinally into the focal plane for rays of any wave-length. The view telescope and collimator have objectives of 2½ inches diameter and of 30 inches focal length. They are fixed at a permanent angle. A Rowland plane grating of 4×2½ inches ruled surface, 20,000 lines to the inch, was used in all the observations. It was found that the third-order spectrum on the more dispersive side was the most satisfactory, and it was used in most instances. The resolving power was sufficient to divide such lines as λ5264.4, etc. For observations below λ6600 the second-order spectrum was used, as it was more brilliant. Absorbing screens were placed in front of the eyepiece when the overlapping orders of the spectrum interfered.

In making the observations, which were all visual, the whole region was hastily surveyed for anything particularly noticeable; then

[1] *Astronomy and Astro-Physics*, **11**, 292, 1892.

a portion was selected for detailed examination. The method was to compare the affected lines in the spot-spectrum directly with Rowland's *Photographic Map of the Solar Spectrum* (*second series*, 1888) and from it to read off the wave-lengths as accurately as possible. For a few lines below B, Thollon's map was used, as Rowland's does not extend sufficiently low in the spectrum. The process of examining each line in the spectrum is very tedious, and progress is necessarily very slow, two or three hours being required in going from C to D.

After the observations were finished, the approximate wave-lengths were corrected to two decimal places with the aid of Rowland's *Preliminary Table of Solar Spectrum Wave-Lengths.* In many cases, however, this was impossible, since many of the most prominent lines in the spot-spectrum are very faint in the spectrum of the photosphere, and are difficult to identify surely with the lines of Rowland's map. In these instances the wave-length was determined by differential measurements with the micrometer from the nearest lines that were surely identified.

The spectrum of sun-spots, as is well known, is composite, consisting of essentially two parts:

1. The nearly continuous spectrum of general absorption.
2. The superposed array of affected Fraunhofer lines.

The absorption spectrum, at times, is resolved into a countless number of fine, closely packed lines. The resolution is most frequently seen in the region from the *b*'s to $\lambda 5100$. It was first seen here by Professor Young in 1883,[1] and afterwards confirmed by Dunér and others. The spectrum has also been resolved into fine lines in the region $\lambda\lambda 6380$–6400 by Professor Young, and also by the writer.[2] In the great spot of February 3, this year, the whole spot-spectrum from C nearly to F was thus resolved, and in the same spot on its return appearance the region $\lambda 6770$ to B was similarly affected. The lines are most closely crowded in the region $\lambda\lambda 5000$–5160; in the lower portions of the spectrum, particularly below D, the lines form groups, rather than a uniform succession of lines as above the *b*'s. The writer doubts whether the greater part of these "band-lines" are lines ordinarily exceedingly faint in the photospheric

[1] *The Sun*, p. 132. [2] *Astrophysical Journal*, **19**, 359, 1904.

spectrum and brought into prominence by the vapors of the spot, but is inclined to the opinion that they are lines not present in the photospheric spectrum at all. This view is supported by the fact that many of these band-lines are very wide (0.5 tenth-meter, in some cases), and fade out at the borders of the spectrum of the umbra (short lines), instead of being pointed, as would be the case of a fine line much widened. They are not nearly so intensely black as the ordinary Fraunhofer lines, but appear more like a wide, fuzzy shade. Of course, there are numerous band-lines that are fine and sharp, extending into and sometimes beyond the spectrum of the penumbra (long lines). These exceptional lines are undoubtedly faint lines in the ordinary spectrum.

There are several bright streaks, or rather partial interruptions in the absorption-spectrum, the most noticeable of these being at $\lambda 5163.7$. Here the spot-spectrum is almost as brilliant as that of the neighboring photosphere. This streak would seem to indicate that the carbon band beginning at $\lambda 5165$, although present in the chromosphere, takes no part in the spectrum of the sun-spot. The band-lines above this particular wave-length show no regularity of arrangement whatever; also the bright streak mentioned above is situated just above the head of the carbon band, a region which should be dark instead of bright.

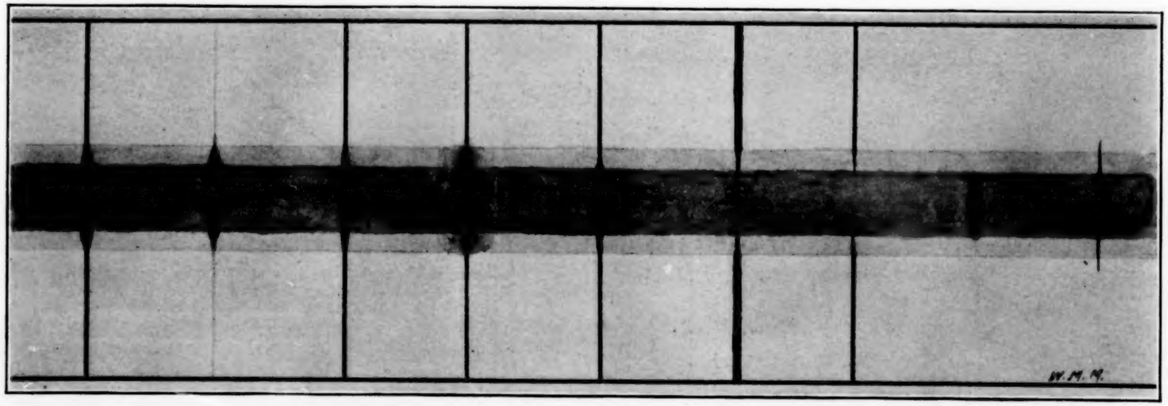
It has been noticed on several occasions that the absorption-spectrum has divided itself into certain dark regions or bands. Nine of these bands, situated below D, were observed early in 1885 at Stonyhurst.[1] At Greenwich in 1880–1883, seventeen were seen in the more refrangible part of the spectrum. One proved identical with a fluting drawn by Young in 1872.[2] Hale in 1902[3] secured some photographs of the spot-spectrum showing similar bands. The wave-lengths of these indicate that they are probably identical with the band-lines in the region above the *b*'s. Taylor Reed at Princeton in 1892 also attempted to photograph the band-lines in the *b* region, and was partially successful.

The array of affected Fraunhofer lines includes the lines widened, reversed, weakened, winged, darkened, and thinned. The figure (Plate

[1] *Monthly Notices*, **47**, 19. [2] *Nature*, Dec. 12, 1872.

[3] *Astrophysical Journal*, **16**, 219, 1902.

PLATE II



Types of Lines in Spectrum of Sun-Spots

II) is an attempt to indicate the appearance of these. The widened lines are the most numerous. Sometimes it is extremely difficult to tell whether a line is actually, or only apparently, widened. Lines which appear considerably widened and winged under low dispersion, when viewed with a more powerful instrument are found not to be widened at all, and sometimes not even winged. It is impossible to say whether the widening under the low dispersion is only subjective, and hence disappears with the high, or whether the widening of the lines is real, and is made imperceptible by the general widening of the line itself under the higher dispersion (as the naked-eye markings on the Moon disappear when viewed with the telescope). Evidence seems to favor the view that the widening under lower dispersion is often subjective, due to the apparent narrowing of the other portions of the line by irradiation, the effect of the brightness of the spectrum outside the spot. A method of testing this has been used which consists in moving the micrometer-wire parallel to the line in question, until the bright space between the wire and the line becomes quite narrow. If this narrow bright space has the same width throughout its extent, the line is certainly not widened. With many lines apparently widened it was found, on applying this test, that the widening disappeared on the side of the line nearest the wire, while the other side of the line still appeared widened, i. e., the line appeared unsymmetrical. A similar effect was produced if the micrometer-wire was moved to the other side of the line. A line that would not stand the test, and yet appeared widened, was called "darkened."

There is considerable difficulty in selecting a suitable scale to record the widening of the lines. Father Cortie's method of estimating the widening of a line in tenths of its normal width was found too uncertain in its application, particularly for the very faint lines. In the table a scale has been used, from 1 to 10, indicating the amount that the line is affected, regardless as to whether it is widened, reversed, etc. The writer heartily endorses Professor Fowler's suggestion[1] that the most satisfactory method of recording the lines is to note the actual intensities of the spot-lines by comparison with neighboring solar lines outside the spot-spectrum. The advantage of this method

[1] *Monthly Notices*, **65**, 206, 1905.

was not appreciated by the writer until the greater part of the observations were made, and then it was too late for any change.

The reversed lines are perhaps the most interesting. Here the widened line is split in two through the spectrum of the spot, the central portion being bright. The fainter lines are usually the most strongly reversed. The widening of these lines is considerable, being sometimes ten times the normal width of the line.

Many of the reversals have been seen not only over the umbra itself, but even more distinctly over the penumbra, and over the photosphere in the immediate vicinity, as instanced by the lines $\lambda\lambda$5225.97, 5250.39, 6082.93, 6137.21, 6173.55. It is to be understood that these reversals outside the umbra were not over "bridges," or bright portions of photospheric matter projected into the spot, but appeared more as if caused by a mass of gas of greater radiating power or greater density, similar to the calcium flocculi which have been so successfully photographed by Hale at the Yerkes Observatory. It would be extremely interesting if spectroheliograms of the Sun could be taken through some of the lines mentioned above.

Of the lines which are always reversed, iron claims eleven, chromium three, and nickel, titanium, and unknown, each one.

The weakened lines may be considered as a sort of "degenerate" reversal. The appearance is similar to that of a widened line, except that the widened part is not so dark as the normal line. With low dispersion these lines often disappear completely in the spot-spectrum, but with high dispersion the widening and the weakening are distinctly seen. It has been found that lines plainly reversed in the region around the spot are frequently weakened when the umbra is directly on the slit of the spectroscope. The weakened appearance is characteristic of the silicon lines in the green portion of the spectrum. A few prominent chromospheric lines in the red are also weakened in the spot.

The D lines in the spot-spectrum, under low dispersion, are the best examples of the winged lines. These wings generally disappear (unless the spot is very large) with the dispersion that the writer has used, no doubt because of lack of contrast, due to their being drawn out to a great extent. It has been noticed that lines which are narrowed, or thinned, without losing intensity, across the spot-

spectrum, are always accompanied by the wings. This is particularly noticeable of lines in the green region, of which the b_3 line is an instance.

Taken as a whole, the most productive portion of the sun-spot spectrum is the region $\lambda\lambda$5700–6600. Here the reversals are most numerous, and the most widened lines are found. Below wave-length 6600 observations are difficult on account of the faintness of the solar spectrum itself; also there are few affected lines. From λ5700 to the *b*'s there are numerous widened lines, it is true, but the widening in general is not very great, the lines being principally winged; the reversals in this region are as a rule narrow, and often scarcely visible. Above the *b*'s the band-lines are exceedingly troublesome, disguising the Fraunhofer lines in such a manner that the detection of their widening is very difficult. Above λ5000 the affected lines are mostly "darkened," while near F the spot-spectrum is frequently so solidly black that scarcely any detail can be made out.

EXPLANATION OF THE TABLE

The first column contains the wave-lengths of the affected lines, as given in Rowland's table. Italics indicate that the line is of special importance. "R" signifies that the line has been seen reversed by the writer.

The second column gives the element, with a few exceptions, as determined by Rowland. Vanadium lines due to Hasselberg are indicated by "VH," lines due to Kayser and Runge are indicated by "KR."

The third column gives the number of times that the line was seen affected in the spot-spectrum. A — indicates that no observations of the line have been recorded by the writer. As the whole region from F–*a* was examined nearly seven times, on the average, the ratio of this number to seven will give a fair estimate of the frequency of the line.

The fourth column gives the intensity of the line in the normal solar spectrum, as determined by Rowland.

The fifth column indicates the conspicuousness of the line in the spot-spectrum, and represents the amount that the line is affected. The scale, as already mentioned, ranges from 10 to –5; a line marked

10 is strongly affected; 1 indicates that the line is only slightly affected. The negative numbers indicate that the line is less conspicuous than in the photosphere, −5 indicating that the line is obliterated.

The sixth column contains remarks on the appearance of the line, and the manner in which it is affected. No remark denotes that the line is simply widened.

When possible, the observations of others have also been incorporated in the table. These are represented by abbreviations as follows:

Ba and Bb = *Bothkamper Beobachtungen*, Vols. 1 and 2, respectively. These contain observations made during 1870, 1871, and 1872, by H. C. Vogel.

Ys = observations by C. A. Young, made at Sherman, Wyo., *U. S. Coast Survey Report for* 1873.

In both of these the wave-lengths of Ångström's atlas were used, and the identification of some of these lines with the lines on Rowland's map is doubftul.

Y = observations by C. A. Young and Taylor Reed, mostly unpublished. These were made at Princeton during the early summer of 1892, with the same instrument that the writer has used, except that the second-order spectrum on the less dispersive side was employed.

L = observations made at the Solar Physics Observatory, South Kensington, under the direction of Sir Norman Lockyer. The number in parentheses indicates the number of times the line was among the "most widened" lines during 1894. This particular period was chosen as most nearly corresponding, in regard to solar activity, to the time during which the writer's observations were made.

C = observations by A. L. Cortie, *Astrophysical Journal*, **20**, 253, 1904; *Memoirs Royal Astronomical Society*, **50**, 29, 1890.

F = observations by A. Fowler, made at the Royal College of Science, South Kensington, *Monthly Notices*, **65**, 205, 1905.

Quotations and remarks following the abbreviations indicate the behavior of the lines as recorded by the various observers.

It will be found, on comparing these lists of lines reported by previous observers with the table, that various lines have been omitted. This was done only when the evidence of the existence of the line in the spot-spectrum was very slight. In the Bothkamp Observations

TABLE OF AFFECTED LINES

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
F**4861.53	*H*	3	30	..	Occasionally reversed. Ba. Bb. See notes.
4862.03	*Cr*	6	0	9	
4863.83	*Fe*	5	2	6	Darkened.
4864.51	*Ni?*	1	1	10	Bb. Lockyer gives enhanced *Cr* line here.
4864.92	*V*	6	0	9	Bb?
4866.46	*Ni*	3	2	8	Winged. Bb.
4868.45	*Ti*	4	0	6	Darkened. Bb.
4870.32	*Ti*	5	1	7	Darkened.
4870.99	*Ni, Cr*	2	3	4	
4871.51	*Fe*	4	5	5	Winged.
4872.33	*Fe*	4	4	5	Winged.
4875.67	*V*	6	1	10	
4876.06	*Fe*	4	2	6	
4876.59		1	1	−5	
4881.74	*V*	5	1	6	Darkened.
4882.34	*Fe*	2	3	3	Winged.
4883.87	*Yt*	2	2	4	Thickened and hazy.
4885.26	*Ti*	6	2	6	Sometimes widened and sometimes darkened.
4885.96	*Cr*	3	0	4	
4886.13	*Cr*	2	00	5	
4888.71	*Cr*	1	00	5	
4890.95	*Fe*	5	6	8	Winged.
4891.68	*Fe*	5	8	8	Winged.
4893.03	*Fe*	1	1	−1	Widened and winged.
4900.09	*Ti, La*	5	2	4	Darkened.
4904.60	*Ni?*	1	3	2	Hazy and widened.
4907.92	*Fe*	2	2	5	Darkened.
4913.80	*Ti*	5	2	5	Darkened.
4915.41	*Ti*	5	000	4	Short line.
4918.19	*Fe*	1	1	−1	Hazy.
4918.54	*Ni*	1	2	−1	Hazy.
**4919.17	*Fe*	2	6	3	Winged. Ba.
4920.68	*Fe*	2	10	4	Winged.
4921.15	*La*	2	0	2	
4921.96	*La, Ti*	5	1	7	Darkened.
4925.75	*Ni*	2	1	−1	Weakened and hazy.
4926.33		6	000	8	
4928.51	*Ti*	3	0	5	Darkened, long line.
4930.98	*Ni*	2	00	2	

TABLE OF AFFECTED LINES—*Continued.*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
4935.05		1	0000	4	Darkened.
4937.90	*Ti*	5	000	5	
4938.99	*Fe*	2	4	7	Long line.
4939.87	*Fe*	2	3	8	Long line.
4942.66	*Cr*	2	2	4	Hazy.
4952.46	*Fe*	2	1	4	Weakened once.
4952.82	*Fe*	5	2	5	Weakened twice.
4953.39	*Ni*	2	2	4	Weakened once.
4954.99	*Cr*	2	2	4	Darkened.
4957.48	*Fe*	2	5	4	Winged. Ba.
4957.79	*Fe*	2	8	4	Winged. Ba.
4958.43	*Ti*	2	00	5	
4965.11	*Cr*	1	1	10	
4966.04	*Mn*	2	00	4	
4968.08	*Fe*	2	3	7	Hazy.
4968.77	*Ti*	2	0	3	
4970.10	*Fe*	3	3	8	Hazy.
4975.53	*Ti*	2	00	4	Darkened.
4978.37	*Ti*	5	00	7	Widened and darkened.
4978.78	*Fe*	2	3	3	Hazy.
4980.35	*Ni*	2	4	3	Winged.
4981.91	*Ti*	3	4	4	Winged. Bb.
4982.99		2	2	8	
4986.16	*Cr*	4	00	5	
4989.33	*Ti*	3	00	4	Darkened, long line.
4991.25	*Ti*	1	3	9	
4997.28	*Ti*	4	0	9	On one occasion was strongest line in this region.
4998.41	*Ni*	1	1	−5	
4999.69	*Ti–La*	1	3	−3	Also winged.
5000.53	*Ni*	2	2	4	Widened and hazy.
5002.04	*Fe*	2	5	4	
5007.91		1	00	6	
5009.83	*Ti–Co*	6	00	10	Darkened, long line.
5013.48	*Cr–Ti*	2	2	5	
5016.34	*Ti*	1	2	5	
5016.66		1	00	4	
5017.76	*Ni*	2	3	4	Winged.
**5018.5	*Ni–Fe*	1	1–4	5	Enhanced line of *Fe*.
5020.21	*Ti*	4	2	7	
5021.78	*Fe*	1	0	6	Hazy.
5022.11	*Cr*	2	000	5	Darkened.
5023.05	*Ti*	3	2	8	Darkened.
5025.03	*Ti*	3	3	8	Darkened.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
5025.75	*Ti*	3	1	7	
5027.31	*Fe*	2	3	5	Winged.
5027.94	*Fe*	2	1	6	Almost obliterated once.
5036.65	*Ti*	3	2	7	Darkened.
5038.58	*Ti*	4	2	6	Darkened.
5039.54	*Ni*	3	00	−4	Always much weaker and hazy.
5040.14	*Ti*	2	3	9	Darkened.
5040.79	*Ti*	3	00	6	Darkened.
5043.76	*Ti*	3	00	2	
5044.39	*Ni-Co-Fe*	1	3	5	Winged.
5045.58	*Ti*	3	00	3	L (10).
5048.61	*Fe*	1	3	5	Darkened.
5052.08	*Cr*	4	0	5	
5053.06	*Ti*	2	0	1	
5060.26	*Fe*	2	3	5	Darkened.
5062.29	*Ti*	1	0	5	L (37).
5064.84	*Ti*	1	3	4	Widened.
5066.17	*Ti*	3	000	5	Darkened.
5071.66	*Ti*	2	0	3	
5073.11	*Cr*	2	1	8	
5080.71	*Ni*	2	4	−3	Hazy.
5081.76		1	000	4	
5081.94		1	000	4	
5082.53	*Ni*	4	2	−4	Once obliterated.
5087.24	*Ti*	4	0	6	L (33).
5109.83	*Fe*	1	2	−3	
5113.30	*Cr*	2	00	3	
5113.62	*Ti*	3	0	3	Darkened.
5120.59	*Ti*	2	0	−2	Widened.
5121.75	*Ni–Fe*	1	2–0	2	Thinned.
5122.16	*Cr*	2	000	7	
5122.30	*Cr*	2	000	3	Hazy.
5122.61		2	000	7	
5122.97	*Co*	3	000	5	
5123.39	*Y*	1	0	8	
5123.64	*Cr*	2	000	4	
5127.86		2	00	3	
*5129.55	*Ni*	1	2	4	Darkened.
5129.81	*Fe*	4	1	−5	Always obliterated.
*5131.64	*Fe*	1	2	−3	Widened and hazy.
5131.94	*Ni*	2	4	3	
5132.84		1	00	4	
5134.70?		—	000	..	L (123). "Band-line."

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
5136.27	*Fe*	1	00	5	Darkened. L (106)
5137.25	*Ni*	2	3	6	Winged.
5138.7		1	....[1]	5	L (130).
5139.4		1	....	5	Band-line.
5139.5	*Fe*	1	4–4	3	Winged. Bb "einseitig nach dem Violett verbreitert."
5140.33		3	0000	10	Band-line.
5141.38		3	000	9	Band-line.
5141.92	*Fe*	3	3	2	Winged. Bb. L (2).
5142.45		3	0000	9	Band-line.
5143.90		3	0000	10	Band-line.
5144.20		3	0000	10	Band-line.
5144.85	*Cr*	3	00	8	
5145.27	*Fe*	3	1	9	Much widened, hazy. Ys.
5145.64	*Ti*	4	0	6	Darkened, long line. Bb.
5146.0		1	....	9	Band-line.
5146.66	*Ni*	2	3	5	Bb.
5147.65	*Ti*	4	0	8	Darkened, long line. Bb. widened toward blue.
5148.0		2	....	7	Band-line.
5148.41	*Fe*	3	3	6	Darkened.
5149–5150		..	....	..	Three heavy shades here.
5150.4		1	....	6	L (9).
5150.74		1	000	5	Band-line.
5152.36	*Ti*	4	0	9	Darkened, long line. Bb. and Ys give the *Fe* line.
5155.30	*Ni*	1	1	4	
5155.94	*Ni*	2	2	5	
5156.24		1	000	8	Band-line.
5156.78		1	0000	9	Band-line.
5156.82		1	00	10	Band-line. L (76).
5159.23	*Fe*	1	2	−4	Bb "stark nach dem Violett verbreitert."
5163.07		1	000	2	Band-line. L (36).
5163.7		6	....	..	Bright streak.
5164.73	*Fe?*	1	1	−3	
5165.59	*Fe*	3	2	−3	Usually weakened.
5166.45	*Cr–Fe*	1	3	4	Bb.
5166.9		1	....	9	Band-line. No corresponding dark line.
b_4**5167.50	*Mg*	—	15	..	Ba. Bb. Ys.
5168.3		1	....	5	Band-line.
5168.83	*Ni*	1	1	−3	

Lines not present in the photospheric spectrum are indicated by (....).

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
b_3**5169.22	*Fe*	5	4	−4	The lower component of b_3, always thinned; the line appears notched on red side. Ys.
b_2**5172.86	*Mg*	—	20	..	Ba. Bb. Ys.
5176.95	*V*	5	000	7	
5177.41	*Fe*	2	0	4	Darkened. Bb?
5178.97		2	000	4	Band-line.
b_1**5183.79	*Mg*	—	30	..	Ba. Bb. Ys.
5184.45	*Fe*	2	2	5	Hazy.
*5186.07	*Ti*	1	2	−3	
*5188.08	*Fe*	1	1	−3	
5188.3		1	....	4	Band-line.
5188.86	*Ti*	1	2	2	Bb "nach dem Violett verwaschen." Ys.
5191.63	*Fe*	2	4	3	Reversed? Bb. Ys.
*5195.11	*Fe*	1	4	5	Winged.
5195.65	*Fe*	1	2	4	Winged.
5196.23	*Fe*	4	1	−3	Usually weakened.
5196.61	*Cr.*	3	0	5	Darkened.
5198.11		2	0	5	
5198.7		2	....	8	Band-line. No corresponding dark line.
*5198.89	*Fe*	3	3	6	Widened and hazy.
*5200.36	*Cr*	1	00	3	
5200.59	*V*	2	0	4	Darkened. Bb?
*5202.52	*Fe*	4	4	5	Winged. Bb. Ys.
*5204.77	*Fe–Cr*	4	3–5	5	Thinned and winged. Bb. Ys. Y.
*5205.90	*Y*	1	0	−4	
*5206.22	*Cr–Ti*	4	5	5	Thinned and winged. Bb. Ys. Y.
*5208.60	*Cr*	4	5	5	Thinned and winged.
*5210.56	*Ti*	2	3	5	Darkened. Bb "sehr stark verbreitert." Ys.
5218.08	*Fe*	3	0	5	
5218.37	*Fe*	3	1	5	
5219.88	*Ti*	5	0	10	Long line. L (8).
5220.25	*Cu* KR	4	000	3	L gives (9) on λ5220.
5221.93	*Cr*	2	0	4	
5222.56	*Cr*	1	00	3	
5222.85	*Ti–Cr*	3	00	3	
5223.35	*Fe*	2	0	3	Darkened.
5223.53	*Ti*	2	0000	5	Darkened.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
5223.79	*Ti?*	1	000	3	Ys?
5224.47	*Ti*	3	0	5	Darkened. Bb "sehr breit nach dem Violett verwaschen."
5224.71	*Ti–Cr*	2	00	4	
5225.20	*Cr-Ti-Fe*	4	00	7	Bb?
5225.70R	*Fe*	3	2	6	Reversed twice. Ys.
5225.97R	*Cr*	2	000	5	Reversed beyond umbra once.
**5226.71	*Ti*	2	2	..	Obliterated? once, reversed? once.
*5227.04	*Fe–Cr*	4	3	−4	Weakened three times.
5228.55		2	1	3	Bb.
5230.38	*Co–Cr*	4	00	8	Bb and Ys both give the *Fe* line.
*5233.12	*Fe*	2	7	5	Winged.
**5234.79		2	2	−3	Thinned and winged.
5235.35	*Co*	2	000	4	Bb?
*5237.49	*Cr?*	2	1	−3	Bb.
5238.74	*Ti*	6	000	7	Bb?
5239.14	*Cr*	6	00	6	
5241.04	*V?*	2	000	2	
5242.66	*Fe*	1	2	6	Bb.
5243.95	*Fe*	1	1	4	Bb.
5247.23R	*Fe*	2	1	4	Narrow reversal once.
*5247.74R	*Cr*	4	2	5	Reversed twice.
5248.09	*Co*	2	000	3	
5249.28	*Fe*	2	00	3	Hazy.
5250.39R	*Fe*	7	2	8	Reversed three times, once in region preceding spot.
5252.28	*Ti*	4	000	7	Bb.
5253.42		2	0000	4	Bb.
5255.30	*Cr*	1	0	4	Bb?
5255.49	*Mn*	3	0	6	
5257.81	*Ti?*	2	0	4	Ys?
5260.14		2	000	5	
**5260.56R*	*Ca*	6	0	5	Reversed three times. Bb.
5264.42	*Ca*	2	3	3	Darkened.
5265.32	*Cr*	2	00	4	
5266.14	*Ti*	4	0	5	
E_2**5269.72	*Fe*	2	8	5	Winged. Bb. Y.
*5275.34	*Cr*	3	00	6	Bb? Ys? Y "triplet, lower line int. 2, and other two disappear."

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
5275.93R	*Cr*	5	1	6	Reversed once, reversed? twice.
**5276.17	*Fe*	1	3	4	Generally not affected. Bb. Ys.
5280.54	*Fe*	1	1	5	Bb "nach dem Violett verwaschen."
5280.80	*Co*	2	00	4	
5282.58	*Ti*	3	00	4	
5284.60	*Fe–Ti*	2	00	3	
5295.95	*Ti?*	6	00	8	Y.
5296.87	*Cr*	3	3	7	Long line. Bb. Y.
5297.41	*Cr–Ti*	4	000	6	Long line. Hazy.
5298.46	*Cr*	2	4	−2	Ys?
5298.67	*Ti*	2	0	−2	Weakened, or reversed? Bb.
5300.15		1	00	3	Y.
5300.93R	*Cr*	3	2	4	Reversed once.
5301.09		2	0000	4	Bb.
5302.48	*Fe*	1	5	4	Bb.
5307.54	*Fe*	1	3	3	
5321.29	*Fe*	2	2	4	Long line.
5324.37	*Fe*	2	7	6	Winged. Y "heavily winged."
*5328.24	*Fe*	2	8	5	Winged. Y "heavily winged."
*5329.33	*Cr*	1	3	5	
5329.96	*Cr*	3	9	5	Hazy.
5340.12	*Fe*	1	6	−2	Winged. Ys.
*5341.34	*Fe–Mn*	2	7–1	−2	Winged. Ys.
5343.15		2	0000	5	Band-line.
*5345.99	*Cr*	2	5	−2	Winged. Ys. Y.
5348.51	*Cr*	2	4	−2	Narrower and winged. Ys. Y.
5349.65	*Ca*	2	4	−2	Narrower and winged. Ys. Y.
5351.26	*Ti*	3	00	4	Darkened.
*5365.07	*Fe*	1	5	7	Winged.
5366.83		3	000	5	
5369.78	*Co–Ti*	2	1	6	Darkened.
**5371.70	*Fe–Cr?*	2	4	8	Winged and thinned. Ys.
5373.91	*Fe–Cr*	3	2	6	Hazy, reversed? once.
5383.57	*Fe*	2	6	5	Winged.
5387.17	*Cr–Fe*	2	0	4	
5387.77	*Cr*	2	00	4	
5389.37		5	000	5	

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
5390.05		2	00	4	
*5393.37	*Fe*	2	5	5	Winged. Y.
5394.85R	*Mn*	6	1	7	Reversed once, partially reversed once, line appeared "twisted." Y.
5396.78	*Ni*	2	000	6	Shaded toward red once
*5397.34	*Fe*	2	7	8	Winged. Ys. Y winged.
5399.67R	*Mn*	2	1	9	Reversed twice.
5401.47		1	0	9	Wide and hazy, reversed ?
5404.36	*Fe*	1	5	4	Winged. Ys.
*5405.99	*Fe*	2	6	8	Winged. Ys. Y "heavily winged."
5407.69	*Mn*	3	1	5	"Twisted" once.
5409.02		3	000	8	Band-line. Y.
5409.34R	*Fe*	1	2	3	Narrow reversal.
*5410.00	*Cr*	2	4	4	Winged. Y.
5412.99	*Mn*	1	00	4	
5413.89	*Mn*	2	00	5	
*5415.42	*Fe–V*	1	5	3	Winged. Ys. Y.
5420.55	*Mn*	4	0	7	"Twisted" once. Ys. Y.
5424.29	*Fe*	2	6	4	Winged. Ys. Y.
**5425.46		1	1	−4	Y "weakened."
5426.47R		7	00	10	Always one of the most prominent lines, reversed once. L (108)
5429.35	*Ti?*	3	00	3	
**5429.91	*Fe*	3	6	4	Winged. Y.
***5432.75R*	*Mn*	6	1	9	Reversed three times. Ys. Y.
*5434.74	*Fe*	2	5	4	Winged. Ys. Y winged.
5436.51	*Fe*	1	1	−2	Winged.
5436.80R	*Fe*	3	1	5	Reversed twice.
5442.63	*Cr*	1	00	7	
**5447.13	*Fe*	2	6	4	Winged. Ys. Y winged.
5453.86		2	000	4	Darkened. Y.
5460.72		6	000	9	Ys. L (20).
5461.76R		4	00	5	Reversed three times.
5462.71R	*Ni*	4	1	9	Reversed four times. Y reversed.
5464.18	*Cr*	1	000	4	
5466.61	*Fe*	2	3	3	Winged.
5467.20	*Fe*	2	1	5	Reversed ? once.
5470.80R	*Mn*	5	0	10	Reversed twice, usually very wide and hazy. Y.
5471.41	*Ti*	5	000	8	Darkened. Y.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
5474.44	*Ti*	3	00	5	
5477.90	*Ti*	4	00	7	Darkened, short line
*5481.5	*Fe–Ti*	1	1	5	Y "duplicity vanishes without apparent widening."
5482.08	*Ti?*	3	00	8	Y.
5483.31R	*Fe*	1	1	4	Narrow reversal.
5483.56	*Co*	4	1	5	Darkened. Y.
5488.37	*Ti?*	2	00	2	Y.
5490.37	*Ti*	5	0	6	Darkened. Ys. L (4).
5493.71R	*Fe*	2	1	5	Reversed twice.
5494.68R	*Fe*	2	0	5	Reversed twice.
5495.10R	*Ni*	1	00	8	
*5497.74	*Fe*	4	5	4	Reversed ? once, generally winged. Y.
*5501.68	*Fe*	2	5	8	Winged. Ys. Y.
5504.12	*Ti*	3	0	4	Darkened. Ys. Y.
5506.09R	*Mn*	3	1	8	Reversed once, generally much widened. Ys. Y.
*5507.00	*Fe*	1	5	7	Winged. Ys. Y.
5511.87R	*Fe*	1	0000	8	
5512.74	*Ti*	2	2	5	
5513.20	*Ca*	2	4	5	Winged.
5514.56	*Ti*	3	2	4	Darkened. Ys.
5514.75	*Ti*	3	2	4	Darkened.
5516.95	*Mn*	2	0	6	Hazy. Ys.
5522.66	*Fe*	1	2	4	
5525.77	*Fe*	2	2	5	Hazy.
5530.99	*Ti*	2	00	3	Darkened. Y.
5537.93R	*Mn*	6	00	8	Reversed three times. Y reversed. Ys.
5538.74R	*Fe*	5	1	9	Reversed four times. Y reversed. Ys.
5544.16R	*Fe*	2	2	5	Narrow reversal twice.
5546.73R	*Fe*	3	2	4	Reversed twice.
5547.22	*Fe–V*	3	1	5	Darkened. Ys. Y.
5556.0		1	....[1]	6	Band-line.
5565.70	*Ti*	5	00	5	Darkened. Y.
5573.08	*Fe*	2	6	5	Winged. Ys. Y.
5573.33		1	1	3	
5582.20	*Ca*	2	4	5	Winged. Y.
5582.9		1	....	5	Band-line.
5583.1		1	....	4	Band-line.
5584.53R	*V?*	4	000	4	Reversed once. Y reversed. Ys.

[1] Lines not present in the photospheric spectrum are indicated by (....).

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
*5586.99	*Fe*	2	7	4	Winged. Bb. Ys.
*5588.99	*Ca*	3	6	4	Widened and winged. Bb. Ys.
5590.34	*Ca*	3	3	4	Widened and winged. Y.
5594.69	*Ca*	1	4	4	Darkened and winged. Ys.
5598.71	*Ca*	1	4	4	Darkened and winged. Bb. Ys.
5600.45	*Fe*	2	3	2	
5619.82R		2	0	4	Narrow reversal once.
5620.72R	*Fe*	2	0	4	Narrow reversal once.
5625.09		4	000	5	Y.
5626.26		3	....	4	Y. No corresponding dark line.
5627.86	*V*	6	00	8	Ys. Y. L (14).
5628.87	*Cr*	3	00	3	Y. L (3).
5636.93R	*Fe*	2	0	4	Reversed once.
5637.63R	*Fe*	1	1	5	Reversed once.
5641.21R		2	1	5	Reversed twice.
5644.37	*Ti*	4	0	5	Darkened. Y.
5645.83	*Si*	—	1	−4	Y "almost disappears."
5646.04	*V?*	3	00	4	
5648.79	*Ti*	3	00	4	Y.
5654.09R	*Fe*	1	1	3	Narrow reversal.
5657.66	*V?*	5	000	5	Reversed ? twice. Y.
**5658.10R	*Y-*	2	2	5	Reversed twice. Y.
5662.37	*Ti*	2	0	4	Ba. Y.
5663.16	*Ti-Fe-Y*	2	1	4	Hazy. Ys. Y.
5667.37R		1	0	9	Wide reversal.
*5667.74R	*Fe*	1	2	9	Wide reversal.
5668.59R	*V*	6	000	6	Reversed once. Y.
*5669.26R		1	1	3	Narrow reversal. Y "almost disappears."
5671.07	*V*	6	0	9	Ys. Y. L (161).
5672.05	*Sc*	6	0	8	Ys. Y. L (156).
5680.15		3	000	4	Y.
5682.87	*Na*	3	5	3	Slightly widened and winged. Ba. Ys. Y.
5684.42		1	1	−3	Hazy.
5684.71	*Si*	2	3	−4	
5684.95		1	0000	8	
5687.06		4	000	7	Reversed ? once. Y.
5688.44	*Na*	1	6	3	Winged. Ba. Ys.
5689.69	*Ti*	5	0	6	Y. L (2).
5690.65	*Si*	2	3	−4	
5694.96	*Cr*	4	0	3	Y.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
5698.55	*Fe–Cr*	2	1	4	Ys? Y.
5698.75	*V*	6	1	8	Darkened. Y.
5700.51	*Cu*KR	7	00	4	Always darkened. Y. L (5).
5701.32	*Si*	1	1	−4	Y "cut out."
5702.54	*Cr*	4	0	4	Reversed? once.
5702.87	*Ti*	2	000	4	Y.
5703.80	*V*	6	1	8	Darkened. Y. L (12).
5707.20	*V*	5	0	7	Darkened. Y. L (5).
5708.32	*Fe*	3	1	2	Ba.
5708.62	*Si*	2	3	−4	
5712.10	*Fe*	5	3	4	Widened on blue side twice. Y.
5712.36R	*Fe*	5	2	5	Reversed five times. Y.
5712.99	*Cr*	2	0	2	Y.
5714.12		2	000	3	Y.
5716.67	*Ti*	7	00	3	Y.
5720.66	*Ti*	4	0	2	Y.
5727.27	*Ti–V*	4	2	8	Not always affected. Y.
5727.87R	*Cr?*	7	00	10	Always much affected. Ba. Ys. Y. L (120). Reversed once.
5731.44R	*V*H	7	00	10	Reversed three times. Ys. Y. L (106).
5731.98	*Fe*	1	4	−2	Hazy.
5737.29	*V*H	6	0	7	Reversed? once. Ys. Y. L (10).
5737.90	*Mn*	1	1	3	Darkened. L gives (107) on λ5737.8.
5739.87R		5	000	4	Reversed once.
5740.37		5	0000	3	
5742.07R	*Fe*	1	2	4	Narrow reversal. Ys. L(1).
5743.18		2	0	5	L (76).
5743.65		4	00	5	Reversed? once. Ys. Y.
5746.64	*A*-	2	000	6	Reversed? twice.
5748.17R	*Fe*	3	2	5	Reversed twice.
5748.57R	*Ni*	5	2	7	Reversed four times. Y reversed.
5752.25	*Fe*	1	4	3	Hazy.
5753.34	*Fe*	1	5	3	Hazy.
5754.88	*Ni*	2	5	2	Hazy. Ba. Y.
5760.57	*Fe*	2	1	−2	Hazy.
5761.05	*Ni*	1	2	−2	Hazy.
5762.49	*Ti*	5	000	4	Y.
5766.55	*Ti*	6	0	4	Y.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
5771.82		1	00	3	Y.
5774.25	*Ti*	6	0	5	Y.
5778.68	*Fe*	2	1	3	Y.
5781.13R	*Cr–Ti*	3	00	5	Reversed twice.
5781.40R	*Cr*	6	0	10	Generally widely reversed, but difficult on account of faintness of line. Y reversed.
5781.97R	*Cr*	6	0	10	Similar to λ5781.40. Y reversed.
5783.29R	*Cr*	5	2	7	Reversed five times. Y reversed.
5784.08R	*Cr*	4	3	5	Reversed three times. Y reversed.
5784.88R	*Fe*	4	1	3	Reversed four times. Y reversed.
5785.19R	*Cr*	5	2	5	Reversed four times. Y reversed.
5785.50R	*Fe*	4	3	4	Reversed twice.
5785.95	*Cr*	3	1	4	Y.
5786.19R	*Ti–Cr*	3	0	3	Reversed twice. Y.
5794.14	*Fe*	2	2	3	Y.
5798.08		4	3	4	Ba.
5804.48	*Ti*	2	0	5	Y.
5804.68	*Fe*	—	0	−5	Y "vanishes in spot."
5823.91		1	00	2	Y.
5828.10		1	0	3	Hazy.
5847.22	*Ni*	4	1	3	Reversed ? once.
5848.34	*Fe*	2	3	2	
5852.44	*Fe*	2	3	2	
5853.54		5	000	3	
5856.31	*Fe*	2	2	3	
5857.67	*Ca*	—	8	..	Ba. Bb. Ys. Y. C. Not recorded by the writer.
5859.81	*Fe*	1	5	3	Winged. Bb. C.
5862.58	*Fe*	1	6	3	Winged. Bb. C.
5866.68	*Ti*	6	3	4	Darkened. Bb. Ys. Y. L (2). C.
5867.79	*Ca*	3	2	2	Ys. Y. L. (18).
5873.44		1	1	1	Ba. L (3).
D_3**5875.98	*He*	3	....	3	Faint shade. See notes.
5880.49R		7	000	10	Faint line, always widely reversed.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
D_2**5890.19	*Na*	4	30	6	Winged. See notes.
D_1**5896.16	*Na*	4	20	6	Winged. See notes.
5899.52	*Ti*	5	1	6	Darkened. C. F.
5902.69R	*Fe*	1	0	8	
5910.20R	*Fe*	3	1	7	Reversed three times. Y.
5916.47	*Fe*	3	3	3	Reversed ? once. F.
5918.77R	*Ti*	3	0	5	Reversed once. Y. F.
5922.33	*Ti*	4	0	5	Darkened. Y. F.
5929.90	*Fe*	1	2	4	Hazy.
5938.04R		6	000	6	Reversed three times. Y.
5941.98	*Ti*	7	00	7	Darkened. Y. F.
5944.95	A (wv)	1	1	5	Darkened. Y. C. F.
5949.56	*Fe*	1	1	4	F.
5952.94	*Fe*	2	4	3	C.
5953.39	*Ti*	5	1	6	C. F.
5956.92	*Fe*	3	4	5	Y. C. F.
5958.46R	*Fe* KR	1	1	8	Reversed once.
5966.05	*Ti*	6	2	7	Ys. Y. C. F.
5978.77	*Ti*	6	1	8	Ys. C. F.
5984.81		3	0000	4	
5989.51	A (wv)	2	0	3	Hazy. Y. C.
5999.92R	*Ti*	7	0	6	Reversed twice. C. F.
6002.97R		4	0000	4	Reversed twice.
6005.77R	*Fe*	6	1	5	Always reversed. C. F.
6007.54	*Ni*	2	1	3	
6008.19R	*Fe*	7	4	6	Always reversed. Ba. Ys. C. F.
6012.45R	*Ni*	5	1	5	Always reversed. Y reversed. C. F.
6013.72R	*Mn*	7	6	5	Reversed four times. C. F.
6016.86R	*Mn*	7	6	5	Reversed four times. C. F.
*6022.02	*Mn*	4	6	3	Reversed ? once. C. F.
*6024.28	*Fe*	1	7	3	Y. C.
6032.0?R		1	....	4	Reversed once. No dark line in spectrum.
6039.95R	*V*	6	0	7	Reversed four times. Ys. C. F.
6053.91R	*Ni*	2	0	5	Reversed once. C. F.
6058.3		4	....	6	Hazy line. Y. C.? F. No corresponding dark line.
6063.08		4	0	5	Ys. C. F.
6064.85R	*Ti*	6	00	9	Always widely reversed. Y. C. F.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
6078.71	*Fe*	2	5	3	Darkened.
6079.23R	*Fe*	7	2	10	Always strongly reversed. C combines both *Fe* lines.
6081.67R	*V*	7	0	9	Reversed three times. Ys. Y. C. F.
6082.93R	*Fe*	7	1	10	Always strongly reversed, reversed in region following spot once. Y reversed. C. F.
6085.47R	*Ti–Fe*	5	2	6	Reversed once. Ys. C. F.
6089.79R	*Fe*	5	1	4	Reversed twice. C.
6090.43R	*Ti–V*	7	2	7	Reversed twice. Y. C. F.
6091.40R	*Ti*	5	0	5	Reversed once. Y. C "obliterated once." F.
6093.03R	*Ti?*	6	000	3	Reversed twice. Y.
6093.37R	*Mn?*	6	00	4	Reversed once. Y.
6096.88R	*Fe*	3	3	4	Reversed once. Y. C. F.
6098.46R		2	0	3	Reversed twice. C. F.
6098.87	*Ti?*	7	00	3	Y.
*6102.94R	*Ca*	7	9	7	Reversed three times. Ba. Ys. Y. C. F.
6111.87	*V*	7	0	8	Reversed? C does not give it! F. Y.
6119.74	*V*	6	1	8	Y. C. F.
**6122.43	*Ca*	4	10	5	Winged. Ba. Bb. Ys. Y. C. F.
6126.44R	*Ti*	6	1	6	Reversed twice. Y. C. F.
6127.85R		3	0000	5	Reversed once.
6129.19R	*Ni*	7	1	3	Reversed twice. C. F.
6131.79R		1	0	4	Reversed once. C.
6132.07R		1	0	5	Reversed once.
6134.81		3	000	4	
6135.58	*V*	7	00	4	Darkened. Y. C. F.
6135.98	*Cr*	3	00	4	
*6136.83	*Fe*	2	8	3	Winged. C.
6137.21R	*Fe*	9	3	15	The most strongly reversed line in the spot; always reversed; reversal generally extends into and beyond the penumbra, though sometimes on the following side only.
*6137.92	*Fe*	2	7	3	Winged. C.
6143.39		2	0000	3	

TABLE OF AFFECTED LINES—*Cont'nued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
6145.23		—	2	..	Y "almost vanishes." C "obliterated once."
6146.45		3	000	4	Y.
6150.36R	*V*	7	0	8	Reversed once. Ys. Y. C. F.
6151.83R	*Fe*	7	4	10	Always reversed. Y reversed. C.
**6154.44R*	*Na*	7	2	7	Reversed three times. Bb. Ys. Y. C. F.
6156.24R		2	00	3	Reversed once. C. F.
*6160.96	*Na*	4	3	6	Winged. Ys. Y. C. F.
6161.50	*Ca*	4	4	5	Ba. Y. C. F.
**6162.39	*Ca*	3	15	4	Winged. Ba. Bb. Ys. Y. C.
6163.97	*Ca*	5	3	7	Reversed ? twice. Y. C.
6170.42	*V*	8	0000	4	Never strongly affected. Y. C.
6170.73R	*Fe–Ni*	2	6	5	Reversed twice.
**6173.55R*	*Fe*	7	5	12	Always widely reversed, frequently beyond penumbra. Ba. C. Y.
6186.93	*Ni*	2	2	5	Y. C.
6188.21R	*Fe*	6	4	8	Always reversed. C. F.
6191.39R	*Ni*	7	6	4	Reversed three times. C.
6199.40R	*V*	8	0	8	Hazy reversal twice. Y. C. F.
*6200.53R	*Fe*	4	6	4	Reversed twice. Ys. C.
6204.83R	*Ni*	2	1	3	Reversed twice. C.
6210.90R		7	00	7	Reversed once. C. F gives origin as *Sc*.
6213.64R	*Fe*	7	6	10	Always reversed. C.
6214.08R	*V*	7	000	4	Hazy reversal twice. C does not give it. F.
**6216.57R*	*V*	7	1	12	Reversed five times. Y. C. F.
*6219.49	*Fe*	5	6	5	C.
*6221.55	*Fe*	4	00	3	F.
6224.71R	*V*	7	000	8	Hazy reversal twice. Ys. Y. C. F.
6226.95R	*Fe*	3	1	3	Reversed twice. C "obliterated once."
6229.44	*Fe*	3	1	4	C "obliterated twice."
***6232.86R*	*Fe*	7	3	9	Always reversed. C. F.
6233.1?R		5	....	4	Strongly reversed twice, apparently no dark line at this point. F.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
6233.41R	*V?*	3	000	7	Reversed once. Y.
**6238.60		1	2	−4	Y "weakened." C "obliterated once."
6240.17		3	00	4	C. F.
6240.86	*Fe*	5	3	6	Reversed? twice. C.
6243.06R	*V*	6	000	4	Hazy reversal twice. Y. C. F.
6243.32R	*V*	7	1	10	Hazy reversal three times. Y. C. F.
6244.03		2	2	−3	C.
6244.68		2	2	−3	C.
6246.54R	*Fe*	1	8	5	Reversed once. C.
**6247.77		2	2	−4	Y "much weaker." C.
6252.05R	*V*	8	00	5	Wide hazy reversal twice. Ys. Y. C. F.
6257.09	*V?*	6	000	3	Y.
6258.32	*Ti*	5	2	5	Darkened. C. F.
6258.93	*Ti*	5	3	5	Darkened. C. F.
6261.32	*Ti*	3	1	4	C. F.
6261.50	*V*	1	0000	2	Y. F.
6265.35	*Fe*	2	5	3	C.
6266.55R	*V*	6	000	3	Hazy reversal once. Y reversed. C. F.
6269.08R	*V*	7	000	4	Hazy reversal once. Y reversed. C "obliterated." F.
6271.48	*Fe*	3	0	3	Hazy. Y. C. F.
6274.87R	*V*	7	00	8	Hazy reversal twice. Y. C. F.
6280.83	*Fe*	2	3	7	Strongly darkened and widened once. Ba. C. F.
6285.38R	*V*	7	00	7	Hazy reversal twice. Y. C "hazy once." F.
6293.03R	*V*	6	000	5	Hazy reversal once. Y. C "darkened once." F. Ba.
6296.58R	*V*	7	0000	7	Hazy reversal three times. Y. C not mentioned. F.
6298.00	*Fe*	3	5	4	Fuzzy. C.
*6301.72	*Fe*	3	7	4	Fuzzy. Displaced toward violet once, also by C. F.
*6302.71R	*Fe*	5	5	7	Reversed without widening three times. Y. C.
6304.1		3	....	6	No dark line here. Y.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
6305.88		6	0000	7	Y.
6311.72	*Fe*	2	1	4	Y reversed. C.
6312.46		4	00	4	C.
6319.46		1	0	−3	C.
6322.91	*Fe*	1	4	9	C.
6327.82R	*Ni*	3	2	5	Reversed once. Y. C. F.
6330.31R	*Cr*	6	1	9	Reversed five times. Y reversed. C. F.
6331.06R	*Fe*	4	2	5	Reversed twice. C.
*6335.55	*Fe*	5	6	4	Y. C.
6336.33	*Ti*	6	000	4	Y.
*6337.05R	*Fe*	5	7	5	Reversed twice. Y. C.
6344.37	*Fe*	4	4	4	Ys. C.
**6347.31		1	2	−4	Hazy. Ba. Ys. C.
6355.25	*Fe*	2	4	5	C.
6358.90	*Fe*	3	6	5	Reversed ? twice. Ys. C.
6363.09R	*Cr–Fe*	7	2	10	Widely reversed three times. Y. C. F.
6366.56	*Ti*	3	000	5	Darkened. F.
6370.57	*Ni*	—	00	−5	Y "extinguished in spot-spectrum."
6392.75		2	0	2	Hazy. C. F.
6400.54R	*Fe*	4	2	4	Reversed once, reversed ? twice. Y weakened. C "weakened once, almost reversed once." F.
6415.20		1	1	−4	Y "obliterated." C "less dark twice."
**6417.13	*Fe* KR	—	1	−5	Y "disappears in spot." C "obliterated six times."
**6432.89	*Fe* KR	3	1	−4	Y "disappears in spot." C.
6439.29	*Ca*	2	8	3	Winged. Bb. Ys. C. F.
6441.16	*Mn ?*	2	000	3	Hazy.
6450.03R	*Ca*	2	6	5	Reversed once. Ba. Bb. Ys. C. F.
6452.54		2	00	4	C.
6455.82R	*Ca*	5	2	6	Widely reversed once. Ba. Y. C. F.
**6456.60		3	3	−4	Y "almost disappears." C "darkened."
*6462.78	*Ca*	3	5	4	Ba. Bb. C. F.
6462.96	*Fe*	3	3	4	Ba. Bb. C. F.
6464.90		4	00	3	Y. C. F.
6471.89	*Ca*	3	5	4	Y. C. F.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
6475.85		4	2	8	Widened and darkened. C.
6482.10R		3	3	5	Reversed without widening once, line "twisted."
6483.03	*Ni*	2	1	5	C.
6494.00	*Ca*	2	6	3	Winged. Bb. Ys? C. F.
*6495.21	*Fe*	2	8	3	Winged. C. F.
6496.69	*Fe*	3	2	−4	
6499.17R	*Fe*	6	1	8	Reversed four times.
6499.88	*Ca*	4	4	6	Winged. Bb. Y. C. F.
6532.0	*V?*	7	0000	5	Ba. Y.
6533.11	*Ni?*	3	0	2	
6538.5		3	....	3	Faint shading.
6546.48	*Ti–Fe*	1	6	−3	Y "weakened." C. F.
6554.47	*Ti*	7	0	9	Ys. F. Not given by C!
6556.31	*Ti*	7	1	9	F. Not given by C!
C***6563.05*	*H*	8	40	..	See notes.
6569.46	*Fe*	3	5	2	Reversed? once. Y. C.
6573.03	*Ca?*	9	1	12	Bb. Ys. Y. C.
6574.47R		9	1	10	Reversed twice. Y. Not given by C!
6575.27	*Fe*	4	2	4	Darkened and winged. C.
6581.45R		5	0	4	Reversed once. Y. C.
6586.55	*Ni*	3	1	3	Darkened. C.
6593.16	*Fe*	4	6	5	Winged. Bb. C.
6594.12	*Fe*	4	4	4	Winged. C.
6597.81	*Cr*	2	1	4	
6599.35	*Ti*	7	00	8	Y.
6605.81		1	000	2	Hazy. Y.
6606.16		1	000	4	
6608.28		2	0	5	C.
6609.36	*Fe*	4	3	5	Darkened. C.
6609.82		2	00	3	
6625.28		7	0	8	Y. C.
6630.27	*Cr*	7	000	5	
6632.71	*Co?*	2	00	2	
6633.99R	*Fe*	3	2	5	Reversed once. C.
6640.00		2	0	2	C.
6661.32	*Cr*	2	00	2	
6663.70	*Fe*	3	3	2	Dark and hazy. Y. C.
6678.24	*Fe*	1	5	4	Darkened. See notes for *He* line.
6696.27		4	1	7	Y.
6698.91		3	0	3	
6703.82		5	1	4	C.

TABLE OF AFFECTED LINES—*Continued*

Wave-Length	Element	No. Obs.	Solar Inten.	Spot-Inten.	Remarks and Other Observations
6705.35		4	1	4	C.
6707.69	*Ti?*	3	000	5	Y.
6710.57		2	0	5	
6717.94	*Ca*	3	5	5	Ys. Y. C.
6726.93	*Fe*	1	2	3	C.
6743.38	*Ti*	6	1	8	Strongly darkened. Y.
6750.41	*Fe*	3	3	4	Darkened. Y.
6752.97	*Fe*	2	1	2	Hazy. Y.
6771.31	*Co*	4	0	4	Y.
6820.63	*Fe*	1	2	4	Reversed? C.
6828.85	*Fe*	1	2	4	Reversed? C.
6840.09		1	1	2	Y.
6842.95R		1	1	5	Reversed once.
6881.98R	*Cr*	3	0	4	Reversed once.
6882.78R	*Cr*	3	1	4	Reversed once.
6883.33R	*Cr*	3	1	4	Reversed once.
6925.13	*Cr?*	1	0000	5	
7068.68		1	2	2	
7107.74		1	0	5	
7111.18		1	1	5	
7122.48		1	4	6	
7131.20		1	3	6	
7148.44		1	3	6	

lines have been given which have not been recorded by any other observer. These, with a few from the other lists, have been omitted. In Cortie's list numerous lines are given whose origin, as given by Rowland, is water-vapor in the Earth's atmosphere. The writer has never observed these lines affected either before or after their publication, although they have been given a careful examination. In regard to the few water-vapor lines in the table, the writer doubts whether they are due solely to water-vapor. They may possibly be solar lines, unidentified as yet, due to elements having lines accidentally coincident with the water-vapor lines, the widening being due to the solar line. An instance is the line $\lambda 5958.46$, given as water-vapor by Rowland, and as *Fe* by Kayser and Runge.

Chromospheric lines are indicated by an asterisk (*); double ** indicates that the line has a chromospheric frequency of 5 per cent. or greater.

This table of 680 lines may be summarized, showing the number of affected lines of each element, as follows: In this summary lines due to more than one element are entered as due to each of the elements. Lines whose assignment to any particular element is doubtful are nevertheless considered as due to the element. The numbers of column 2 are not included in column 3.

Element	Total No. Lines Affected	Always Reversed	Occasion-ally Reversed	Doubtfully Reversed	Weakened or Obliterated
Iron	210	11	38	8	21
Unknown	136	1	21	4	5
Titanium	121	1	9	1	5
Chromium	79	3	13	2	5
Nickel	47	1	11	1	7
Vanadium	43	..	19	3	..
Calcium	24	..	4	1	1
Manganese	20	..	9	1	1
Cobalt	11	..	..	..	..
Sodium	6	..	1	..	..
Silicon	5	..	..	..	5

Yttrium, 5; lanthanum, 4; magnesium, 3; hydrogen, 2; copper, 2; helium, 1; scandium, 1; lines, attributed to more than one element, 40; total number reversed, 138.

NOTES ON THE BEHAVIOR OF METALLIC LINES IN THE SPECTRUM OF SUN-SPOTS

Iron.—The total number of iron lines seen affected is 210, about 31 per cent. of the total number of lines. Of these, 49, or 23 per cent., have been seen reversed by the writer.

Sir Norman Lockyer, after an extended study of the widened lines in sun-spots, has been led to the view that the selection of lines to be widened and darkened varies from epoch to epoch of solar activity. In 1886,[1] from a study of sun-spot observations made on a fixed plan during six years, he was led to the conclusion that as we pass from minimum to maximum the lines of known chemical elements gradually disappear from among those widened, their places being taken by lines which are unidentified.

[1] *Proc. R. S.*, **51**, 256.

To quote Miss Clerke:[1]

The evidence for the progressive change was indeed slight, except as regarded iron; and iron alone was taken account of in the confirmatory Stonyhurst observations.[2] So far as they went, however, they were decisive, and all the more so that they covered a different spectral range (B to D) from that (D to F) examined at South Kensington. They showed demonstratively that, throughout the disturbed interval between January 1884 and October 1886, iron lines were all but completely replaced by "unknown" lines in the list of those affected in spots, while they duly reappeared upon the restoration of photospheric tranquility.

Lockyer, after an investigation of the widened lines in sun-spots during an additional period of eight years, has reiterated his conclusions as follows:[3]

The period embraced by the observations practically enables us to study what has taken place at two successive sun-spot minima and maxima . . . . At the minima the iron lines are prominent among the most widened lines, at the maxima we find only lines about which nothing is known.

Cortie in his earlier observations, as quoted above, confirmed these conclusions. However, his views have since changed, for he states:[4]

My observations afford no evidence of crossing points when faint lines of vanadium and titanium give way to lines of iron at a period between the sun-spot maximum and minimum.

One important distinction has nevertheless been established by Cortie, namely, that the iron lines, while not displacing other faint lines, are more affected in tranquil spots than in the torn and ragged type. Since the former predominate at periods of minimum disturbance, and the latter at maximum periods, the statistical outcome is that the spectral variations depend only upon the individual spot, and do not indicate any periodic change in the general solar temperature.

The writer's observations hardly confirm those of Lockyer. More lines of iron have been observed affected during the period of observation than those of any other element, including lines of unknown origin. The period of the writer's observations, although

[1] *Problems in Astrophysics*, p. 90. [2] *Memoirs R. A. S.*, **50**, 43.

[3] *Proc. R. S.*, **57**, 200. [4] *Astrophysical Journal*, **20**, 264, 1904.

short, is near the date of the sun-spot maximum, when, according to Lockyer, there should be very few iron lines affected. Even in the region investigated by him (D to F) the iron lines predominate.

The writer's observations agree with Cortie's conclusions in regard to the widened lines. The reversed lines are equally prominent in both types of spots. Of course, from the short period of observation no definite conclusion can be drawn, but no change in the number of reversed lines was noticed in connection with the type of spot.

From the fact that the reversals are equally prominent in each type of spots, while the widening in general is not, one concludes that the widening of many of the lines in the minimum type of spot may be subjective; probably due to the fact that the minimum spot presents a larger umbra in proportion to the whole area of the spot, and hence the dark spectrum of the umbra is more prominent, making it very difficult to differentiate the real widening from the subjective.

Titanium and chromium.—The manner in which the lines of these two elements are affected can best be discussed by treating them together. Titanium has 121 lines affected, chromium 79, but with the reversed lines chromium leads with 16, while titanium has 10. The titanium lines are more conspicuous in the spot-spectrum, by reason of their being, in the large majority of instances, darkened without much widening, while the chromium lines, although equally faint in the solar spectrum, are more widened and less darkened, i.e., are hazy, in the spot-spectrum. Three chromium lines, $\lambda\lambda 5781.40$, 5781.97, and 5783.29, are always reversed. The titanium reversals are less frequent, only one line, $\lambda 6064.85$, being always reversed.

Nickel.—Of the lines of this element in the solar spectrum, 47 have been affected in that of the spot. Twelve of these have been reversed; the line $\lambda 6012.45$ is always so affected. A fair proportion of the nickel lines are weakened in the spot-spectrum, the line $\lambda 5039.54$ particularly.

Vanadium.—The importance of the vanadium lines in the spectrum of sun-spots was first shown by Professor Young in 1892.[1] Cortie in 1898 also noted the lines of this element.[2] The behavior of these lines is perhaps more striking than that of any others. They are, with few exceptions, exceedingly faint in the spectrum of the photo

[1] *Princeton College Bulletin*, **4**, 58. [2] *Monthly Notices*, **58**, 370.

sphere, yet in the spot they are relatively more conspicuous than other lines. The total number of lines affected is 43, which is fully four-fifths of the vanadium lines in this region. Of these, 44 per cent. have been seen reversed. The lines $\lambda\lambda 6224.71$, 6243.06, 6243.32, and 6252.05 have been seen so widely reversed at times as to give the effect of a pair of hazy lines, rather than a single line split in two. The above lines have all been given by Cortie as very much widened. The reversing of the vanadium lines seems to show no preference for any particular type of spot. Possibly the reversals are more distinct when the spot is near the limb, but the evidence of this is so slight as to warrant no definite conclusion.

Calcium.—The calcium lines present no striking peculiarities, the total number affected being 24, while only 4 have been seen reversed. The calcium lines with low dispersion are nearly all widened, but with high dispersion the widening disappears and the lines appear merely winged. The H and K lines were first noted as always reversed by Professor Young at Sherman, in 1872; this has been confirmed by Hale, Deslandres, and others. These lines are beyond the spectral region examined by the writer, and no attention was given to them.

Manganese.—This element, strange to say, has the greatest proportion of reversed lines, 45 per cent. of its lines being thus affected. The lines reverse occasionally, showing no preference for any particular type of spot. One very interesting change, however, has been noted in connection with the great spot of February 1905. At the first observations of this spot, on February 3 and 4, the lines $\lambda\lambda 5394.85$, 5399.67, 5432.75, 5470.80, and 5506.09 were all noted "strongly reversed;" on the return of the spot, observations on March 3 showed that these lines were no longer reversed, but instead were all extravagantly widened and very hazy. It is to be regretted that this change could not have been noted in the red lines (below $\lambda 6000$) also, but, unfortunately, the region of the spectrum observed on the earlier date did not include those lines. Observations in March showed them as widened only. No similar change has been noted in the lines of any other element, probably because, owing to the extent of the whole region investigated, it was rarely that more than one observation could be made on a spot in any given portion of the spectrum.

Silicon.—These lines have always been weakened, when affected in the spot-spectrum.

Sodium.—The sodium lines behave in various ways. The red pair at $\lambda 6154.44$ and $\lambda 6190.96$ are usually affected; the former line has been reversed on several occasions. Both are chromospheric lines. The D lines are always both affected alike. They are probably the first lines ever to have been seen reversed in the spectrum of a sun-spot. This observation was by Professor Young in 1870; since then there have been many other reversals observed, of which no account need be given. It is, however, sufficient to say the reversal of the D lines is by no means an unusual occurrence, although the writer himself has never seen them distinctly reversed. The nearest approach to a reversal was in the great spot of February 1905, when the D's were each broadened to about three times their normal width, the widened part being somewhat less dark than the normal line. The whole was surrounded by wings extending a considerable distance on each side of the lines. On October 14, 1904, the D's were seen with a faint streak through the middle of each line. The lines were not widened, however, at that time, except for the usual wings. The weakening of the central portion of the lines in neither of these instances was of such a character that the lines could be called reversed. Of the green pair at $\lambda 5682.87$ and $\lambda 5688.44$, the former is the more affected; both are usually winged.

Magnesium.—The *b*'s are the only lines of this element which have been recorded as affected in spots. There are records of their being seen reversed by Young, Naegamvala, Crew, and others. Their reversal seems to be less frequent than that of the D's.

Helium.—The writer has never seen the red line at $\lambda 6678.37$ affected by a spot, but it has been seen on several occasions by other observers. Observations of the yellow line D_3 are more numerous. Professor Young recorded it as a dark shade in 1870. Cortie gives two observations of it as a bright line in 1883 and 1885.[1] The Greenwich observers give several instances of its visibility during 1882, and it has been seen numerous times since then. The general behavior of the line is somewhat uncertain. It seems to show itself from time to time, independent of the particular type of spot. The

[1] *Memoirs R. A. S.*, **50**, 55, 1890.

great spot of February 1905, at its first appearance, did not show it at all, but on the reappearance of the spot, while still very near the limb, D_3 was distinctly seen extending over its whole area. The line has been seen on several other occasions by the writer, but always as a faint shade. The rare visibility of the line may be an indication that the spots lie well down in the solar atmosphere and, unless there is some unusual activity, have no great effect on the upper solar atmosphere. One such instance was noted and will be given under hydrogen.

Hydrogen.—Only two hydrogen lines lie in the region of the spectrum investigated, C and F. Of the two, C is more affected. F is generally a reproduction, on a small scale, of C. The lines are not widened as the metallic lines are, but are, nevertheless, frequently reversed. The reversals are different from those of the metallic lines, which are simply widened and split in two by a bright streak through the middle of the line. The hydrogen reversals take place in all portions of the spot, umbra, penumbra, and over bridges; they are usually caused by overlying prominences. These can often be seen by opening the slit of the spectroscope, although it is difficult to distinguish more than the general outlines, on account of the great brilliancy of the spectrum under these circumstances.

Distortions in the C line due to motion in the region of the spot are very frequent. Many observations have been recorded. But distortions are very seldom seen directly over the umbra, such signs of activity being almost always in the penumbral regions. As an instance of this may be mentioned the observations recorded by Crew and by Hale in the spot of February 1892.[1]

In some remarks on observations of the spot of September 1898, Fényi states[2] that quiescent prominences do not occur over areas of spots, which are the scene of transitory eruptive phenomena. The writer does not agree with him in excluding quiescent prominences from sun-spots. It is true that the eruptive kind are more numerous, but both the C and F lines have been seen reversed over spots by the writer many times without showing any distortion whatever. Between spots and prominences there seems certainly to be some connec-

[1] *Astronomy and Astro-Physics*, **11**, 308 and 310, 1892.

[2] *Astrophysical Journal*, **10**, 333, 1899.

tion, but just what, it is difficult to say. An instance of this connection was observed on October 31, 1904, during the observations on a spot near the Sun's limb. At about 12 M. the writer was examining the spectrum of the spot in the region near C, and noticed that the line had become much distorted near the southern edge of the spot-umbra. By moving the spectroscope, this distortion could be traced to the limb and beyond it. On making the slit tangential and opening it, a large zigzag prominence was seen, extending, as measured, 70,000 miles beyond the limb. The displacement of the C line indicated a motion toward the observer of approximately 250 miles per second. In less than five minutes the whole prominence had faded away, and the region was again quiet. During the time that the prominence was visible, a hasty glance was taken at the D_3 line, which was seen as a faint shade in the region of the spot from which the prominence started. This instance is noteworthy from the fact that the prominence could be seen arising almost out of the umbra.

Unknown.—Next in number of affected lines to those of iron are the lines which have not been identified with any terrestrial element. The total number of these is 136, or approximately 20 per cent. of all the lines observed. These lines are affected in every variety of way, widened, reversed, weakened, etc., indiscriminately, with the exception that as in the case of the iron lines the percentage of reversals is greater in the red end of the spectrum. Only one line of this class at $\lambda 5880.49$, is always reversed.

In regard to the closely packed band-lines, those given in the table are only a few of the most prominent ones, no attempt whatever being made to give a complete list.

NOTES ON THE PROBABLE LEVEL AND CONSTITUTION OF SUN-SPOTS

A comparison of the chromospheric lines with the lines affected in the spot-spectrum affords the following conclusions:

a) Lines of considerable frequency (5 per cent. or more) in the chromosphere are, with two exceptions, very little affected in spots.

b) "High-level" chromospheric lines are not affected in spots.

c) Lines most affected in spots are either absent from, or of low frequency (less than 5 per cent.) in the chromosphere.

These conclusions favor the view that spots are at least below the chromosphere.

The interesting question arises why some lines of a given element are affected and others not. The lines most affected may be enhanced lines or short lines in the arc, but, as the writer was unable to find a table of such lines extending below the green region, it was impossible to make a comparison. It has been stated by Jewell[1] that many of the lines in the solar spectrum have their origin at different levels. In this, the writer believes, is a solution of the question. That the lines most affected are caused by vapors at a low level is apparently indicated by the fact that they are not chromospheric lines, and it is manifest that the spots are at the level which produces the lines that are most affected.

The vapors situated low down in the photosphere, and consequently under greater pressure and at a higher temperature, would give rise (the bright background of the photosphere being absent) to an emission-spectrum; this, in conjunction with the cooler and less dense layer above, would produce a dark line with bright center, i. e., a reversed line. It has been noted that the reversed lines are usually the fainter Fraunhofer lines, the lines H, K, F, and C being excluded, as it is fairly well established that the reversals of these lines are due to overlying prominences, flocculi, etc., and not gases low down in the spot.

The fact that the most widely reversed lines are faint may be explained by assuming that the vapors that produce these lines are intimately mingled with the photospheric clouds, and do not extend to a great elevation above them. The probably continuous spectrum of the photosphere is not subject to so great an absorption by this thin layer, and the resulting dark lines are thus not very intense. A striking example of this is afforded by the vanadium lines. Observations would seem to indicate that the vanadium vapors are situated in and among the photospheric clouds, as evidenced by the fact that the vanadium lines are nearly all faint in the solar spectrum. This shows that there may not be a sufficiently deep layer of the vapor to cause strong absorption; also only one line (frequency 3 per cent.) is visible in the chromosphere. The appearance in the

[1] *Astrophysical Journal*, **4**, 138, 1896.

spot-spectrum is precisely what might be expected. Nearly every vanadium line is affected, and presents the appearance of a wide, hazy reversal.

The behavior of the titanium lines might at first glance seem to contradict the above theory, in that they are faint lines in the solar spectrum, are very prominent in the spot, and likewise prominent in the chromosphere. These objections may be removed, however, by assuming that the titanium vapors are at a slightly higher level than those of vanadium. This seems in general to be indicated by the fact that the faintest titanium lines in the spectrum are the most affected in the spot, while the stronger lines are less prominent in the spot and more prominent in the chromosphere. Also there are few reversed lines, and those are not chromospheric. The titanium lines are nearly always darkened without much widening, indicating a slightly stronger absorption in the spot.

These views of the writer agree in the main with those of Cortie, who has suggested[1] that the level of sun-spots may be that of the vapors of such elements as have an atomic weight of about 50.

The purely visual observations of sun-spots indicate that the spot is a rent or perforation in the photosphere. Whether they are actual depressions or not, the observations of the apparent widths of the penumbra at various distances from the limb are too uncertain to determine. It can hardly be believed that the umbra is at a higher elevation than the penumbra, for it is unquestionable that the penumbral filaments overlie the umbra, and often unite forming bridges across it.

Whether the spot is caused by up-rushes, according to the earlier theories of Faye and of Secchi, or by down-rushes, as suggested by Lockyer and by Oppolzer, is not as yet determined. Line-shifts in the spot-spectrum, with the exception of those due to hydrogen, are very rare, and those given in the table are regarded by the writer as mostly spurious, due to neighboring faint lines. In only one instance has a distinct shifting been noticed, which would favor either of the above theories. This was on February 24, 1905, when every line in the spectrum was shifted toward the blue by about 0.05 tenth-meters. The shifting was not over the umbra of the spot,

[1] *Monthly Notices*, **58**, 373.

but in the region of a facula overlying a rift at one end of the spot. The following day it was noticed that a small umbra had developed in exactly the region of the shifting, indicating, in this instance, that the small spot was formed by an upheaval. Also the behavior of the manganese lines, already noted, may be considered as evidence that the heated vapors in the spot had moved upward, and, becoming cooler, produced stronger absorption, and the much-widened lines.

From the radiometric investigations of Langley, Frost, and Wilson, we learn that the photospheric radiation decreases as we approach the limb, while that of the spot changes but slightly. This can be explained in one of two ways: either the spots are high above the photosphere, as maintained by Howlett and others, and hence subject to less absorption; or the total radiation from the spots is of a different type from that of the photosphere, and therefore the absorption of the solar envelopes exerted on the photosphere would be different for the spot.

In regard to the first hypothesis, the spectroscope seems to indicate that the level of the spots is below the chromosphere; hence it may be assumed that the absorption of the upper solar envelopes is exerted on the spots as well as on the photosphere.

The second hypothesis has been suggested by Professor Young. The photosphere is rich in radiation of short wave-lengths, while the spots are noticeably deficient in radiation of this nature, as shown by the lack of detail in the upper regions of the spot-spectrum. It has been shown by Vogel and others that the violet light of the photosphere becomes relatively much more feeble as we approach the Sun's limb, than does the red. The solar atmosphere then absorbs to a considerable degree the short wave-length radiations of the photosphere, while the total radiation of the spot, not possessing these short waves, is not subject to this great absorption, and passes through the solar atmosphere nearly undiminished in intensity. It is thus possible that the total radiating power of the spot may be as high as or higher than that of the surrounding photosphere, and so indicate by the thermoscope a higher "temperature" for the spot.

The writer is inclined to the opinion that sun-spots are probably caused by the heated vapors of the interior slowly oozing through and vaporizing the clouds of the photosphere. The vapors from

below, at first hot, would become cooler through expansion and exposure, resulting in the reformation of the photospheric clouds in the shape of veils and bridges, which are generally heralds of spot-decay.

That the spots are regions of relatively high temperature has been suggested by Wilson,[1] and is borne out by the reversed lines. Moreover, if the spots were a cooler region, condensation would take place tending to destroy the character of the spot.

In conclusion, the writer wishes to thank most heartily Professor Young, whose advice and suggestions have been of the greatest value in carrying out this research.

[1] *Monthly Notices*, **65**, 224.

THE OBSERVATORY,
Princeton, N. J.,
March 30, 1905.

POSTSCRIPT

As this is going through the press, detailed observations of the great February spot by Fowler have come to hand (*Monthly Notices*, **65**, 513). He states:

> It appears that the high-level lines (chromospheric) were not among those intensified in the spot, while the common lines were chiefly those of iron, chromium, and calcium, which appear as strong Fraunhofer lines.

This is in complete agreement with the writer's observations.

A comparison of the chromospheric lines given with the spot lines recorded at Princeton shows that, excluding the hydrogen and helium lines, among the long lines (high-level) given by Fowler, four are recorded by the writer as widened: the D sodium lines, the lines $\lambda 5018.63$ and $\lambda 5276.17$, both due to enhanced iron. Seven others are recorded as weakened or obliterated; two of these, $\lambda 5169.22$ and $\lambda 6456.60$, are due to enhanced iron; the others, $\lambda 5425.46$, $\lambda 6238.60$, $\lambda 6247.77$, and $\lambda 6347.31$, are still unidentified; $\lambda 6432.89$ is *Fe* KR.

The line $\lambda 6232.86$ given as a chromospheric line of frequency 5 per cent. by Young is not recorded by Fowler. This line is one of the strongest spot lines, being always reversed. Similarly the manganese line $\lambda 5432.75$ is given by Young with chromospheric frequency

8 per cent., and is not recorded by Fowler. This line is also strong in the spot, being reversed three times.

To those contemplating investigations on the spectra of sun-spots the writer would like to suggest that a comparison of observations on the same spot at different periods of its development will be more fruitful than will the comparison of observations on different spots. The behavior of the manganese lines noted above is an example of what perhaps may be expected.

JUNE 14, 1905.

SYNCHRONOUS VARIATIONS IN SOLAR AND TERRESTRIAL PHENOMENA

By H. W. CLOUGH

I. THE THIRTY-SIX-YEAR CYCLE IN TERRESTRIAL PHENOMENA

Numerous attempts have been made to discover definite periods of recurrence of meteorological phenomena, and many so-called weather cycles have been announced, ranging in length from a few days to a hundred or more years. The cycle discovered by Dr. Brückner is, however, the only one which has gained general acceptance among meteorologists. Brückner in 1890 published an elaborate monograph[1] in which he seemed to demonstrate the existence of a cycle of about 35 years in terrestrial climates, utilizing not only all available meteorological observations from about 1700, but in addition a vast amount of material affording indirect indications of climatic changes, including records of the advance and retreat of glaciers, the time of grape harvest, the opening and closing of navigation by ice, and the occurrence of severe winters, by which he was enabled to trace back the period nearly 1000 years. Briefly, his conclusion is that the whole Earth undergoes climatic variations or oscillations, cold and wet periods alternating with warm and dry periods. The mean dates or epochs of the former are 1700, 1740, 1780, 1815, 1850, and 1880; and of the latter, 1720, 1760, 1795, 1830, and 1860.

A careful examination has been made of Brückner's results, and where the author has given in general terms intervals of time, 10 to 20 years in length, embracing periods during which the values of the meteorological elements were above or below the average, I have attempted to assign in place of these relatively long periods single lustrums or years, representing as nearly as possible the average date or the epoch of each extreme. Comparison of the epochs of the meteorological elements as regards their sequence is thus facilitated. Besides utilizing the data which Brückner published, exten-

[1] *Klimaschwankungen seit 1700*, Vienna, 1890.

sive use has been made of data derived from other sources, and corresponding epochs have been determined in like manner for several additional meteorological phenomena.

Table I contains the meteorological epochs. The series of epochs for barometric pressure from 1740 to 1830, pressure-gradient, variability of temperature, frequency of easterly winds, frequency of West Indian hurricanes, frequency of thunderstorms, and grain prices are my own additions to Brückner's data. The remaining portions of the table are reproduced in all essential respects from Brückner's work, the main difference being, as above stated, that the mean epochs have been more accurately determined.

1. Temperature

Instrumental records of temperature are available from about 1730 in Europe, and from about 1780 in the United States. Brückner regarded this element as the one upon which all other elements depend, either directly or indirectly, and I also find that the epochs of temperature almost invariably precede those of precipitation and pressure. He concluded that the variations in temperature in his 35-year cycle are synchronous over the entire globe, but a careful examination of his lustrum means leads me to the conclusion that a slight retardation of the epochs occurs in southern as compared with northern Europe. This retardation is quite clearly shown by a comparison of the lustrum means of Scandinavia and northwestern Russia with those of southern Europe (p. 227).

The fluctuations are more regular and of greater amplitude in high latitudes, the extreme range of variation, considering the unsmoothed lustrum means, being 1°.0 to 1°.5 C. in northern Europe. In the tropics the fluctuations are somewhat irregular and of small amplitude.

The retardation and decreased amplitude of the oscillations in low latitudes is probably due to the fact that the circulatory activity of the atmosphere decreases toward the tropics, and the waves of high and low pressure, with their attendant temperature variations, which traverse the atmosphere in middle and high latitudes, penetrate into low latitudes slowly and with diminished intensity. These conditions are shown on the daily weather map in winter, the cold

waves appearing first in high latitudes and gradually extending southward with a diminution of intensity. By analogy we infer that the long-period atmospheric oscillations appear earliest in high latitudes, and ultimately extend into low latitudes with diminished intensity.

2. Precipitation

European rainfall records extend back to 1688, when observations were begun at Paris. From 1725 they are sufficiently numerous for accurate determination of epochs. In the United States, although isolated and fragmentary records date from 1738, it is not until about 1810 that sufficient records are available, and accordingly historical accounts of great floods in the Mississippi and Ohio Rivers were utilized to determine the epochs in the eighteenth century. The epochs in the table refer to the interior of Europe and the United States, and the variations in these two regions appear to be synchronous. Brückner finds that, unlike temperature, the epochs of precipitation are not synchronous over the whole globe, but that there are oceanic regions where the variations are the reverse of those over the interior of the continents. These regions he characterizes as "temporary" and "permanent" exceptions. Examples of these exceptional regions are found along the Atlantic coast of the United States, the coast of Ireland, and on some of the islands of the Atlantic Ocean. He considers that the oceanic areas experience rainfall variations opposite to those of the continental areas, so that a compensatory relation between continent and ocean seems to exist as regards rainfall. He also shows that the amplitude of the oscillation increases with the continentality of the region, the greatest range being in western Siberia, where 2.3 times as much rain falls in the rainy period as in the dry period.

While Brückner inferred that no progressive retardation in the epochs of rainfall occurs, with change either of longitude or latitude, yet a careful inspection of his rainfall data seems to lead to the conclusion that, as with temperature, the extremes occur earlier in high latitudes, the retardation averaging probably five years at the tropics. In the equatorial regions the epochs of rainfall are probably synchronous with those in high latitudes. This is shown by the fluctuations of the Nile, which synchronize closely with those of rainfall in northern

Europe. Brückner's curves of rainfall variations (pp. 181, 182), showing the changes of the secular oscillations from north to south in the Old and New Worlds, illustrate this fact of retardation in low latitudes.

Comparison of the epochs of temperature and precipitation shows that cold periods are attended by an excess and warm periods by a deficiency of precipitation over the continental areas. A tendency, however, toward a retardation in the epochs of precipitation is clearly evident, the average amount being about six years.

3. Height of Water Surface of Lakes and Rivers

Supplementing and confirming the series of rainfall epochs are those obtained from records of fluctuations of the water surface of inland seas, lakes, and rivers. One series of epochs in the table refers to the oscillations of lakes without outlets in various regions of the globe, the data being largely derived from historical and traditional accounts of high and low water. Another series comprises epochs derived mainly from records of mean stages of European rivers and lakes in river courses. Both series are reproduced without change from Brückner. The general agreement of these epochs with those of rainfall is readily apparent.

4*a*. Barometric Pressure

The records which Brückner employed in his investigation of pressure variations in Europe and surrounding regions were those compiled by Dr. Hann in his work on the pressure distribution in Europe.[1] These records begin in 1826, and the epochs in the table, beginning with 1831–1835, are those determined by Brückner. The epochs prior to 1825 were determined by me from the records compiled by Buys-Ballot,[2] and the entire series of epochs relate to pressure variations in Europe only.

Correlation of pressure and rainfall variations.—Brückner found that the curves of rainfall and pressure for Europe are nearly exact counterparts of each other as regards synchronism of phase and amplitude of variation, excessive rainfall and low pressure being coincident. This relation between pressure and rainfall which he

[1] *Die Vertheilung des Luftdruckes über Mittel-und Süd-Europa*, Vienna, 1887.

[2] *Met. Jahrbuch*, 1870.

found for Europe during the period from 1826 to 1885 is confirmed by the epochs of pressure from 1740 to 1825. He did not investigate pressure variations in America, but it is found that a relation, the reverse of that for Europe, prevails in the northeastern portion of the United States, particularly in winter. In this region relatively high pressure and excessive precipitation prevailed about 1850 and 1882, and low pressure and deficient precipitation prevailed about 1835, 1865, and 1900. This relation was derived from investigation of rainfall variations in the upper Ohio valley and pressure variations at Toronto. A similar relation exists for the region of low pressure about Iceland, as will be shown below. The explanation of this inversion in pressure between Europe and northeastern United States evidently lies in the fact that the belt of maximum storm frequency attains its most southerly position in America, extending over the region of the Great Lakes and the St. Lawrence valley; while in Europe the path of greatest frequency lies far to the northwestward, being traced over the Atlantic midway between Iceland and the Faroe Islands, thence over extreme northern Scandinavia.

In his investigation of pressure and rainfall variations over the whole Earth, Brückner discovered that during the continental wet periods relatively high pressure, or pressure above the normal, prevails over the North Atlantic Ocean in the vicinity of Iceland and the Faroe Islands, also over the equatorial belt of low pressure in the northern part of the Indian Ocean and the China Sea. At the same time the pressure is below the normal throughout the permanent belt of high pressure which extends from the Azores northeastward through central Europe to the interior of Russia and in winter over Siberia. The reverse is true for the dry period. The pressure variations in winter and summer for the wet and dry periods are shown in the following table by Brückner, presenting variations from the normal for the season:

Period	North Atlantic		Western and Central Europe		Eastern Europe and Siberia	
	Winter	Summer	Winter	Summer	Winter	Summer
Wet	Above	Below	Below	Below	Below	Above
Dry	Below	Above	Above	Above	Above	Below

From the foregoing facts Brückner deduced the generalization that wet periods are characterized by a diminution of local and seasonal differences of air-pressure, or a weakening of sea-level gradients. This implies a decrease in the annual pressure-gradient over middle latitudes, a decrease in the seasonal gradient between continent and ocean, and a decrease in the amplitude of the seasonal variation at any given locality. In other words, the gradient between the North Atlantic Low at Iceland and the North Atlantic High at the Azores is less during the wet periods than during the dry periods. The gradient between Iceland and central Europe also varies in like manner. Furthermore, the pressure over the interior of the continents during the wet periods is lower in winter and higher in summer than during the dry periods.

Variation in the activity of the general circulation.—In his discussion of these relations Brückner concluded that the increase in pressure in the polar and equatorial regions, the simultaneous decrease over middle latitudes, and the decrease in the amplitude of the seasonal variation, during cold, wet periods, imply a decreased activity of the general circulation. He attributed the cold periods to a decrease in solar radiation, and accordingly assumed that during such periods the temperature-gradient between equator and pole should be less than during warm periods, resulting in a diminished circulatory activity. Since, however, his table of temperature fluctuations for different latitudes showed that greater amplitudes prevailed in high latitudes, he concluded, in order to account for this discrepancy between theory and fact, that the slight fluctuations in the tropics were caused by discontinuity in the records and to a masking effect of the eleven-year period of Köppen. It will be shown below, however, that a weakened pressure-gradient in middle latitudes, as between Iceland and the Azores, and a decreased amplitude of the seasonal variation—conditions occurring during the cold, wet periods—probably denote greater circulatory activity. *A priori*, a decrease in solar radiation would result in a diminished temperature-gradient between equator and pole, so that a paradox is apparently involved in attributing the cold periods to a decrease in solar radiation.

From a consideration of some phenomena of the general circulation

it appears probable that changes in pressure, similar to those which characterize cold periods, result from an increase in circulatory activity. The distribution of air-pressure over the surface of the Earth, considered as a rotating globe, is mainly the resultant of two factors. The first factor is the temperature-gradient between the equator and the poles caused by their varying insolation. The resulting circulation tends to form a belt of relatively low pressure in the equatorial region, a belt of high pressure near latitude 35°, a belt of low pressure near latitude 65°, and a region of relatively high pressure around the poles. This is the pressure distribution resulting from the circulation of the atmosphere over an ideal water surface. The second factor is the distribution of land surface over the Earth which distorts the ideal courses of the isotherms parallel with the equator, resulting in a seasonal temperature-gradient between continent and ocean. The effect of this factor is to modify the ideal distribution by the formation of high-pressure areas during winter over the continents in the northern hemisphere, and of corresponding low-pressure areas during summer. This interaction of land and water, summer and winter, results in large seasonal inequalities of pressure. The seasonal charts of pressure in the northern hemisphere, therefore, show isobars greatly distorted from the ideal courses, parallel with the equator, which largely prevail in high latitudes in the southern hemisphere with their preponderance of water surface, and in the free air above the irregularities of land surface that offer great resistance to pressure readjustments in the lower atmosphere.

If the general atmospheric circulation be accelerated, thereby overcoming to a greater extent the inertia of the lower atmosphere, we should expect, in the first place, the influence of the second factor, which distorts the ideal isobars, to be weakened and the resulting distribution to be more uniform over the Earth, the differences between the pressure on land and water being thereby lessened. This tendency toward more uniform pressure distribution with increased circulatory activity implies a decrease in pressure over the regions of high pressure which prevail in winter over the continents and in summer over the oceans, and a corresponding increase over the regions of low pressure, or a general diminution of the seasonal control

which results from the interaction of land and water. A further result of an acceleration of the general circulation is an increased centrifugal force of the great circumpolar whirls, crowding the subtropical belts of high pressure nearer the equator and causing the belt of average storm-tracks to descend to lower latitudes. The pressure over middle latitudes to the southward of the path of average storm tracks will therefore decrease, while that over the polar and equatorial regions will increase. These changes in pressure caused by greater circulatory activity are apparently the same as those found by Brückner to prevail during the wet periods as compared with the dry periods. The conclusion, therefore, is that the cold, wet periods are characterized by an increase in the rapidity of the atmospheric circulation, attended by greater decrease in the temperature of the polar as compared with the equatorial regions, and consequently an increase in the temperature-gradient between pole and equator.

Dr. Hann in a recent paper[1] discussed the abnormal variations in the pressure-gradient between the Azores and Iceland, and concluded that an increase in the gradient is a consequence of an increased intensity of the atmospheric circulation. But it is possible that even with increased gradients at sea-level the gradients in the upper atmosphere may at the same time be diminished, so that the intensity of the general circulation is decreased. In this investigation the instances of abnormal variations during certain months may be misleading, since the mean distribution of pressure over the Earth in any given month may be the result of so many factors that the effect of variations in the intensity of the general circulation is largely masked. It is conceivable that there may be other causes, aside from the thermal gradients between pole and equator, continent and ocean, that bring about pressure variations. Hence only annual or lustrum means in which the effect of other factors is probably eliminated, should be considered. By reducing upward, we obtain the pressure distribution in the upper atmosphere which is immediately related to the general circulation. It may easily be shown

[1] "Die Anomalien der Witterung auf Island in dem Zeitraume 1851 bis 1900 und deren Beziehungen zu den gleichzeitigen Witterungsanomalien in Nordwesteuropa," *Sitzungsberichte der Akad. der Wiss. in Wien.*, Jan. 1904.

that the higher the level to which the reduction is made, the less becomes the influence of variations in the sea-level pressure, so that at great heights the pressure is almost entirely a function of the surface temperatures and the direction of the isobars approximates closely to that of the isotherms at sea-level. For example, at 30,000 feet a variation of 0.01 inch in the sea-level pressure becomes a variation of 0.003 inch, while a variation of 1° F. becomes a variation of 0.04 inch, showing that variations in the sea-level pressure become almost negligible at this elevation. During the cold periods, therefore, the diminished pressure-gradient at sea-level will have but slight effect on the pressure-gradient at high levels, while the increased temperature-gradient will be reflected in an increased pressure-gradient; consequently an increase in the intensity of the general circulation will result.

4*b*. Pressure-Gradient

A series of epochs which confirm the relation above stated is afforded by the variations in the annual pressure-gradient over the region from the high-pressure belt of central and western Europe northwestward to Iceland. They are: maximum gradient in 1790, 1831–35, 1860, and 1895; minimum gradient in 1815, 1840, and 1875. During cold periods, therefore, a decrease in the pressure-gradient occurs over western Europe. This is true also for the gradient between the Azores and Iceland.

5. Frequency of Easterly Winds

Since the direction of the pressure-gradient over western Europe implies a prevailing southwesterly surface current, a weakening of the average gradient would seem to indicate an increase in the frequency of easterly to northerly winds; and observations show this to be the case. Numerous records of wind-direction frequency have been examined, and at stations north of the permanent high-pressure belt a variation in the frequency of easterly winds was disclosed, corresponding with the variations of pressure-gradient, such that a decrease in the gradient and an increase in the frequency of easterly winds coincide. This relation is found to exist also in the United States, and is probably universally true over the northern hemisphere where the gradient involves a maximum frequency of westerly winds.

Tracks of storm-centers.—Since the main track of low-pressure areas over the North Atlantic is from mid-ocean northeastward, skirting the coast of Norway, the prevailing winds over Europe, north of the ridge of high pressure, are westerly to southerly. Hence an increase in the frequency of easterly winds at any point would imply that more storm-centers pass to the southward of the locality. In other words, the average latitude of storm-tracks is lower than usual. A diminished pressure-gradient likewise implies a lower average latitude of storm-tracks. The conclusion therefore is that in cold periods the storm-tracks lie farther south than in warm periods. This shifting to the southward of the belt of average storm-tracks was shown above to be a probable result of the increased circulatory activity which was assumed to characterize cold periods.

Additional confirmation of this relation results from a count of storms passing north and south of Chicago during the period 1873–1900, disclosing a maximum ratio of southern to northern storms about 1878, the center of a cold period, and a minimum ratio about 1895, the center of a warm period. The number of storms passing north and south for each year, with the ratio of southern to northern storms, is shown in the following table:

Year	N.	S.	Ratio S.:N.	Date	N.	S.	Ratio S.:N.
1873	80	40	0.50	1887	68	34	0.50
1874	73	38	0.52	1888	61	32	0.52
1875	66	44	0.67	1889	74	31	0.42
1876	70	35	0.50	1890	80	36	0.45
1877	68	40	0.59	1891	72	35	0.49
1878	55	43	0.78	1892	81	25	0.31
1879	70	38	0.54	1893	76	33	0.43
1880	85	32	0.38	1894	77	26	0.34
1881	53	31	0.58	1895	73	30	0.41
1882	64	26	0.41	1896	75	27	0.36
1883	62	38	0.61	1897	62	28	0.46
1884	67	35	0.52	1898	71	26	0.37
1885	56	32	0.57	1899	72	25	0.35
1886	65	42	0.65	1900	81	36	0.44

6. Variability of Temperature

An important deduction has been drawn from a study of the variability of mean daily temperature, or the average change in mean temperature from one day to the next, considered without regard to sign. The variations of the annual means of this quantity from

year to year at any place are due to varying meteorological conditions, such as amount of cloudiness, distance from storm-centers passing north or south, intensity of storm-development, velocity of storm-movement, etc. It is found, however, that the latter element chiefly influences the variability, so that at stations situated within or near the belt of average storm-tracks, girdling the Earth north of the forty-fifth parallel, the changes in this element are an index to the varying velocity of movement of storm-centers. This relation is based upon a study of the variations in the two phenomena in the United States. Yearly values of this element are available for several Russian stations,[1] enabling the variations to be traced from about 1750, and show a tendency to fluctuate with mean epochs as given in the table. The close synchronism of these epochs with those of temperature is readily apparent.

The inference drawn from this series of epochs is that cold periods are characterized by increased variability of temperature, which probably implies an increase in the velocity of storm-movement, and consequently an increase in the circulatory activity of the atmosphere during these periods.

Velocity of storm-movement.—Further confirmation of this deduction has resulted from an investigation of the average velocity of movement of storms in the United States. The average velocity for each year from 1872 to 1901 has been computed from the monthly means given in the *Monthly Weather Review*, and the resulting values, when smoothed, show a decrease from a maximum about 1882 to a minimum about 1895. The average yearly velocities are shown in the following table:

1872...	26.2	1878...	22.4	1884...	32.7	1890...	30.8	1896...	26.7
1873...	25.2	1879...	31.7	1885...	28.7	1891...	27.1	1897...	25.8
1874...	26.8	1880...	30.5	1886...	27.7	1892...	29.6	1898...	26.0
1875...	28.2	1881...	33.6	1887...	28.6	1893...	29.8	1899...	27.1
1876...	27.2	1882...	28.8	1888...	30.0	1894...	24.2	1900...	29.5
1877...	25.7	1883...	32.2	1889...	28.2	1895...	26.1	1901...	27.8

Thus the conclusion derived from a consideration of the general atmospheric circulation, that an increase in activity occurs during the cold periods, is confirmed by two independent investigations.

[1] Wahlen, *Tägliche Variation der Temperatur an 18 Stationen des Russischen Reiches.* St. Petersburg, 1886.

7. Frequency of West Indian Hurricanes

The frequency of tropical hurricanes has been shown by Poëy and Meldrum to vary in a period approximately 11 years, or that of the solar spots, and it appears to be fairly well established that they reach a maximum frequency shortly after the sun-spot maximum. An examination of Poëy's table of West Indian hurricanes from 1750 to 1873[1] discloses in addition a long-period variation with well-defined maxima in 1786, 1817, and 1838, and minima in 1762, 1798, 1823, and 1864. The remaining epochs in this series were derived from his catalogue of hurricanes from 1493 to 1855, and from the records of the Weather Bureau, beginning with 1873. The epochs of maximum frequency coincide with the wet periods of the Brückner cycle, particularly with the corresponding epochs of precipitation in the United States.

The conditions favorable to the development of tropical hurricanes are thus probably connected with the general circulation, and cannot be regarded as of purely local origin. Years in which the movement of storms of middle latitudes is most rapid and their paths extend far southward, indicating an increased activity of the general circulation, are signalized by frequent hurricanes in low latitudes. Furthermore, observation of the daily weather map shows that the development of West Indian hurricanes is usually coincident with an increase in the velocity of movement of high- and low-pressure areas in the United States.

8. Frequency of Thunderstorms

Von Bezold,[2] in his investigation of thunderstorm frequency, arrived at the conclusion that periods of maximum thunderstorm frequency are conditioned upon high temperature as well as a solar surface free from spots. His table of relative numbers for Europe yields epochs approximately as follows: maxima in 1768, 1797, 1822, and 1852; minima in 1783, 1814, and 1837. Comparison of these epochs with those of temperature in Europe shows that thunderstorms are least frequent during cold periods, thus confirming v. Bezold's conclusion in regard to temperature conditions.

[1] *Comptes Rendus*, **77**, 1223, 1873.

[2] "Ueber gesetzmässige Schwankungen in der Häufigkeit der Gewitter," *Sitzungsberichte der math.-phys. Klasse der B. Akad.*, **4**, 1874.

9. Frequency of Severe Winters

Pilgram's catalogue of severe winters was used by Brückner to extend his cycle back nearly 1000 years, and confirmatory evidence is at hand to prove the validity of the method he employed. For every fifth year, as 800, 805, 810, etc., he gives a number which represents the total number of severe winters recorded in the 20-year period of which it is the center. The epochs in the table were derived by me from Brückner's table (p. 268), and are intended to represent as nearly as possible the centers of periods of maximum and minimum frequency of severe winters. They approximately coincide with the general epochs of low and high temperature. These variations in temperature are shown graphically on Chart 2, the epochs being plotted with a uniform amplitude of variation.

This series of epochs is the result of careful consideration of all data available and comparison with the mean epochs derived from other climatic records; it departs from Brückner's table of warm and cold periods from 1020 to 1890, and omits in the sixteenth century one oscillation which should be regarded as secondary. The third and fourth columns give the intervals, derived from the epochs of maximum and minimum frequency of severe winters, embracing each three successive periods. Thus in column 3, the first number, 120, is the interval between the two epochs 1000 and 1120. The longest three-period interval in the series is 125, and the shortest is 90. If there is an additional oscillation in the sixteenth century, the three-period intervals in that century would be reduced to 75 years, which is highly improbable, since the latter interval is the length of two average periods, and there is no other three-period interval less than 90 years in the entire series.

The average length of this cycle was computed by Brückner from his table of cold and warm periods derived from his table of the frequency of severe winters. He writes (p. 270): "The table embraces the years 1020 to 1890. Within this period of time of 870 years we enumerate twenty-five cold periods and twenty-five warm periods, hence twenty-five complete oscillations. We find therefore the average length of one oscillation to be 34.8 years." But, as shown above, the number of complete oscillations should be reduced by one, making the length of the cycle 36.25 years.

10. Duration of the Season of Navigation

The dates of the opening and closing of navigation on rivers, lakes, and harbors in Russia have been recorded for 150 years at many localities and in the vicinity of St. Petersburg from the middle of the sixteenth century. Brückner derived his data from Rykatschef's memoir on ice conditions in Russian waters.[1] The epochs of this series were derived from Brückner's tables and are well defined, affording a most valuable indirect method of exhibiting climatic variations. They average about 6 years later than those of severe winters.

11. Time of Grape Harvest

The time of beginning of the grape harvest in France and southern Germany has been recorded in some localities for many hundred years, and these records were utilized by Brückner to determine secular climatic variations. In this series of epochs, as with that of the frequency of severe winters, a rearrangement of dates in the sixteenth century was necessary in order to eliminate one oscillation in Brückner's table. The epochs synchronize well with those of the severity of winters, occurring on the average five years later. Late harvests, therefore, characterize periods of excessive precipitation.

12. Grain Prices

In his discussion of climatic oscillations, Brückner did not refer to fluctuations in grain prices as an index to these changes, but in a later paper[2] he compares prices and climatic variations in Europe during the past 200 years, and finds a relation such that high prices occur during or shortly after periods of maximum rainfall.

In order to confirm this relation and extend the comparison as far back as possible, Rogers' *History of Prices and Agriculture in England* was consulted. These volumes contain an exceedingly valuable collection of prices of grain and commodities, beginning with 1265. Rogers incidentally mentioned the possibility of a seasonal cycle being discovered in the fluctuations of grain prices. He writes:[3]

[1] *Ueber den Auf- und Zugang der Gewässer des Russischen Reiches.* St. Petersburg, 1887.

[2] "Der Einfluss der Klimaschwankungen auf der Ernteerträge und Getreidepreise in Europa," *Geographische Zeitschrift*, 1895.

[3] Vol. I, Pref., p. xi.

"Lastly, as there were no regular means for supplying deficiencies in the produce of the home market by foreign importation, the prices of necessaries such as corn give no small insight into the course of the seasons, if, as I do not dare to assert, such a cycle can yet be found."

Examination of Rogers' statistics of grain prices discloses fluctuations in the prices of wheat, rye, barley, etc., corresponding with those of temperature, periods of high prices occurring shortly after periods of low temperature, with an average retardation of about seven years. Thus the series of epochs of grain prices serve to confirm the epochs of severe winters. This is especially the case in the earlier centuries. In the last two centuries disturbing influences have contributed to mask the fluctuations, and accordingly from about 1700 onward, grain prices in continental countries were also used in determining the epochs.

These epochs synchronize very well with the epochs of the time of grape harvest, and the conclusion is that the same stress of weather which tended to retard the maturity of the vine in France caused deficient grain harvests in England.

II. THE THIRTY-SIX-YEAR CYCLE IN SOLAR PHENOMENA

Brückner discussed at considerable length the origin of the secular climatic variations which he discovered, and concluded that it must be referred to a cosmical source. He examined the sun-spot relative-numbers of Wolf, but found no evidence of his 35-year cycle in their variations. Nevertheless, he stated it as his conviction that such a variation must exist in solar phenomena, and that the climatic oscillations on the Earth point to a solar cycle, to be discovered later. He thought it probable that the cycle would be shown in the variations in the intensity of solar radiation.

Dr. W. J. S. Lockyer[1] pointed out that a cycle of about 35 years exists in the variations of the interval from one sun-spot minimum to the succeeding maximum. He writes: "There is some law at work which introduces a secular variation by retarding the sun-spot maxima in relation to the preceding minima." He considers this as the source of the Brückner cycle.

[1] "The Solar Activity, 1833–1900," *Proc. R. S.*, **68**, 285, 1901.

Professor A. Wolfer,[1] on the other hand, discusses Dr. Lockyer's results, and concludes from examination of the relative-numbers and epochs from 1750 that no regular periodicity exists, and that "the continued existence of a 35-year cycle is not yet demonstrated." It will be shown, however, in this paper that a 36-year cycle in the variations of solar phenomena undoubtedly exists, and also that a much longer cycle exists, underlying the 11 and 36-year cycles.

Variations in the length of the eleven-year cycle.—In Table II, "Sun-Spot Epochs" (Wolfer), the epochs of sun-spot maxima and minima, determined by Wolf and revised by Wolfer, are shown in the first two columns. The third and fourth columns contain the successive intervals, maximum to maximum and minimum to minimum. It is well known that the so-called 11-year cycle is only an average of these varying intervals. Uniting these intervals into one column, and smoothing them by the formula $\frac{1}{3}(a+b+c)$, we have a series of numbers, column 5, which vary more or less regularly. These numbers are plotted to form the first curve in Chart 1. By inspection of the data in this and in the preceding columns, the dates in columns 6 and 7 are obtained. These epochs represent the centers of periods of maximum and minimum intensity of the processes which result in the 11-year cycle of solar activity, a rapid completion of this cycle indicating a maximum intensity of solar activity, as will be shown below. The mean length of this cycle of variation in the length of the 11-year period, based on the epochs from 1615 to 1880, is 35.7 years. This cycle of solar activity is thus derived from nearly 300 years' observations of sun-spots, since the invention of the telescope, during which period the successive 11-year epochs of maxima and minima can be relied upon as approximately correct.

Fritz[2] has compiled a list of all recorded observations of sun-spots previous to 1610, when their regular observation by the telescope began. Nearly all of these observations are derived from ancient

[1] "Revision of Wolf's Sun-Spot Relative-Numbers," *Monthly Weather Review*, **30**, 171, 1902.

[2] "Die Perioden solarer und terrestrischer Erscheinungen," *Vierteljahrsschrift der Naturforschenden Gesellschaft*, Zürich, 1893.

Chinese annals, beginning about 300 A. D.; a few records are from European sources. From this list Fritz deduced approximate epochs of sun-spot maxima, where sufficient observations were available, and showed that a period averaging about eleven years has existed during the entire interval. In the same paper he gives a list of years during which auroras have been recorded, with the number of displays observed each year, and derives therefrom a series of probable epochs of auroral maxima. From these two independently determined series, supplemented by early records of great hailfalls, he deduces a series of probable sun-spot maxima from 301 A. D. to 1616, there being only twenty-seven epochs missing for which no adequate data exist. From 1057 to 1616 there are only six epochs missing from his list, which is reproduced in column 1 of Table III —"Epochs of Sun-Spot Maxima" (Fritz). The required epochs have been supplied and are designated by an asterisk. One change was made in the epochs, namely that of 1603, which is obviously too early, and in the table 1605 was substituted. The second column of the table contains the intervals between these epochs of maxima. From the data in these two columns the epochs in columns 3 and 4 were derived, being a continuation backward of the epochs in columns 6 and 7 in Table II. They are less exact, however, having been derived from epochs of maxima only, which are subject to considerable uncertainty. Nevertheless, the mean interval between these epochs during the period 1050 to 1600 is 36.6 years, which is very nearly identical with that obtained from the table of Wolfer's epochs, thus confirming in a remarkable manner the general accuracy of these "probable maxima" of Fritz.

The epochs of maxima and minima of the 36-year solar cycle from 1000 to 1900 are shown graphically on Chart 2.

The missing epochs of Fritz's list of "probable maxima" from 301 A. D. to 1057 have been approximately determined, and probable epochs of the 36-year cycle derived. Table III contains the 36-year epochs from 295 to 1100. The average length of the 11-year cycle from 301 to 1104 is 11.00 years, while from 1104 to 1894 it is 11.13 years. The mean length, therefore, during 144 periods from 301 to 1894 is 11.063 years. The average length of the 36-year cycle from 300 to 1900 is 36.5 years, the mean from 300 to 1100 being practically the same as from 1100 to 1900.

The sun may therefore be regarded as a variable star, whose mean period of variation undergoes a cyclical variation in length. Chandler has shown that this phenomenon is characteristic of many variable stars.

Lockyer's conclusion that a 35-year period exists which alters the time of occurrence of the maxima in relation to the preceding minima, is evidently only partially true, since the interval maximum to minimum likewise undergoes a similar variation. The solar-spot activity is periodically accelerated and retarded, and this action is primarily manifest in the varying length of the 11-year spot cycle, since it operates continuously throughout the entire interval to accelerate or retard the occurrence of the two phases.

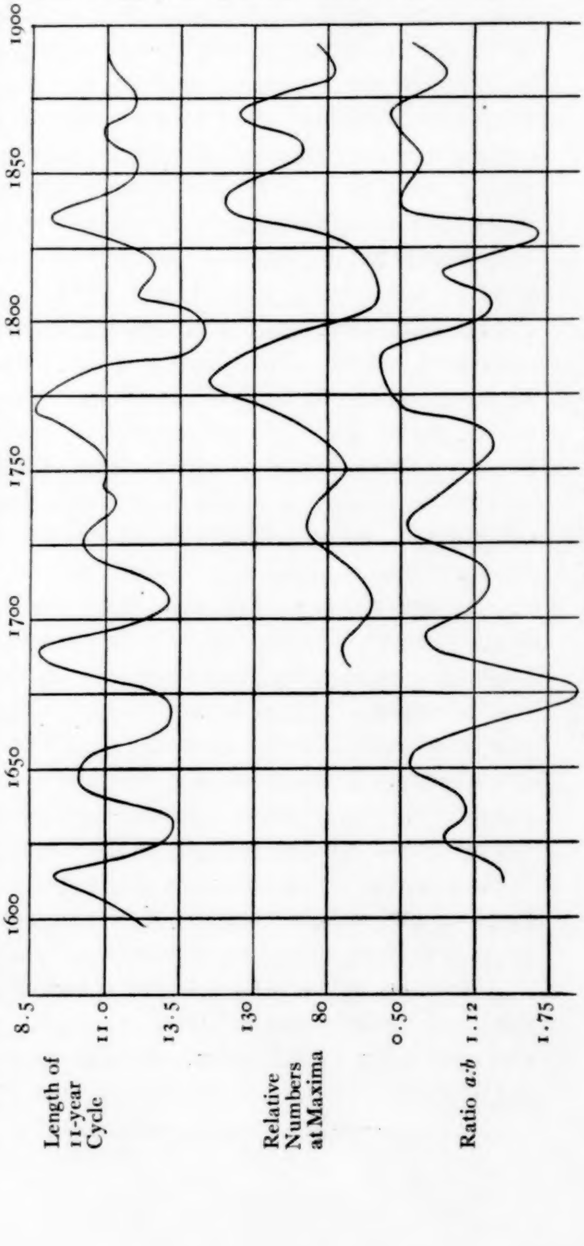


CHART I.—The 36-Year Solar Cycle.

Variations of the relative-numbers. — In Table II, column 8, are given the relative-numbers at the time of each maximum, beginning with 1685. Prior to 1750 the average relative-number for the year in which the phase occurred is

given; subsequently, the highest value contained in Wolfer's table of smoothed numbers is placed opposite the corresponding epoch. Comparing the variations in these numbers with the variations of the 11-year period, shown in column 5, the conclusion is evident that periods of rapid development of the cycle of changes averaging 11 years are also those of increased intensity of solar activity, as evidenced by the increased frequency of spots. That is to say, when the period is shorter the sun-spot number is larger. The second curve on Chart 1 displays graphically these variations in the relative-numbers.

Wolf[1] showed that the shortest periods brought the most acute crises. This relation for the 11-year period, first stated by Wolf, was confirmed by Dr. Halm,[2] who also found that "in the individual spot-periods the maximum occurs earlier in proportion as the development of the spots is more rapid." This inverse relation between the intensity at a maximum and the interval from the preceding minimum follows as a deduction from the general law, which may be expressed as follows: The solar spottedness varies inversely with the length of the cycle of activity. It will be shown below that this law applies to the 36-year cycle as well as to the 11-year cycle.

One oscillation in the series of relative-numbers at maxima, column 8, is absent, although existing in the variations of the 11-year interval, thus resulting in a 59-year interval from the maximum of 1778 to that of 1837. The abnormally low numbers for the maxima of 1805 and 1816 correspond with the unusually long sun-spot periods between 1788 and 1830.

The average relative-number for each 11-year period, minimum to minimum, is shown in column 9, opposite the corresponding maximum epoch. These numbers are from the paper by Fritz quoted above. The variations of this series are synchronous with those of the maximum relative-numbers in the preceding column.

Comparing the variations in the length of the 11-year cycle with those of the relative-numbers, a retardation of the epochs of the latter is evident, averaging 5 years.

Variations of the ratio a:b.—In columns 10 and 11 of Table II are given the intervals of the 11-year cycle, minimum to maximum and maximum to minimum. Representing the former by a and the latter by b, the successive ratios $a:b$ were computed and are shown

[1] Wolf, *Astronomische Mittheilungen*, No. 12, 1861. [2] *A. N.*, **156**, 33, 1901.

in column 12, opposite the corresponding maximum epochs. Chart 1 exhibits in graphical form the variations of these ratios. Inspection of this series of ratios discloses variations parallel with the 36-year variation in the length of the 11-year period; the ratio varies directly with the length of the period. The epochs of these variations of the ratio occur about 7 years later than the corresponding epochs of the variations of the length of the period.

Comparison of the variations of the relative-numbers with the variations of the ratios *a:b* shows that the two series of numbers vary inversely, with epochs of variation nearly coincident.

Column 13 of the table contains the ratios *a:b*, smoothed by taking the mean of each five successive values. These smoothed ratios disclose a long-period variation, with a maximum about 1685, and a minimum about 1865. In other words, the sun-spot curve flattens out about 1685, so that the intervals *a* and *b* approach equality, or *a* is even greater than *b*.

Referring to the series of epochs of the 36-year cycle, columns 6 and 7, it is apparent that the intervals between the epochs are not uniform in length, being relatively long about 1700 and short about 1850. Thus the long-period variation in the ratio *a:b* corresponds with a similar long-period variation in the length of the 36-year interval, the ratio varying directly with the length of the period. Hence the ratio *a:b* varies directly with the length both of the 11- and the 36-year cycles.

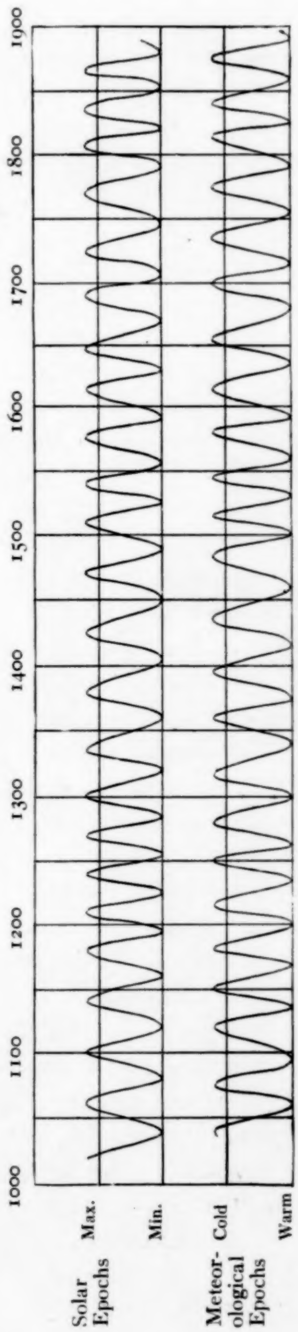


CHART 2.—Epochs of the Thirty-six-Year Cycle.

The long-period variations in the ratio *a:b* are generally synchronous with the secular variations of spottedness, columns 8 and 9, varying inversely with the latter, in conformity with a similar relation shown above to exist in connection with the 36-year cycle.

Reliability of Wolfer's epochs.—The accuracy of the sun-spot epochs in the seventeenth and eighteenth centuries, particularly those from 1788 to 1805, has been questioned by some investigators. It has been assumed that a uniform period exists, and that the irregularities which are shown by Wolfer's epochs arise from imperfections of the records. But the records of magnetic declination which are available from about 1780 show that variations in the range exist with epochs practically coinciding with Wolfer's epochs. The epochs of auroral frequency from 1700 also confirm the sun-spot epochs. Furthermore, the evidence for the 36-year cycle, cited above, proves that variations in the length of the 11-year period really exist and are of a periodic nature. The normal period is eleven years, subject to alternate acceleration and retardation during a cycle averaging 36 years. The synchronism between the variations of the ratio *a:b* and the variations of the 11-year interval furnishes additional evidence of the substantial accuracy of the epochs of Wolfer.

Epochs of magnetic declination range.—These epochs, given in Table IV, columns 1 and 2, were derived from the table of smoothed means of declination range in a paper by Fritz,[1] with the exception of those subsequent to 1878, which are those determined by Ellis in his discussion of the Greenwich magnetic observations. The epochs of the 36-year cycle, columns 6 and 7, were derived in the same manner as those of the sun-spots in Table II, and the two series of epochs are almost exactly synchronous. The table is particularly instructive as affording indirect confirmation of the accuracy of the sun-spot epochs of Wolfer, especially those in the latter part of the eighteenth century.

The average range at each epoch of maximum and minimum is given in columns 8 and 9.

Epochs of auroral frequency.—The 11-year auroral epochs, given in Table V, columns 1 and 2, are those determined by Fritz,[2] and

[1] *Viertel. d. Natur. Gesell.*, Zürich, 1884.

[2] *Die Beziehungen der Sonnenflecken zu den magnetischen und meteorologischen Erscheinungen der Erde*, Haarlem, 1878.

have been treated similarly to the sun-spot epochs. The resulting 36-year epochs, columns 6 and 7, seem to occur about 5 years later than the corresponding 36-year sun-spot epochs.

The secular epochs of maximum and minimum visibility of the aurora are given in columns 8 and 9 of the table, and apparently occur about 8 years later than the epochs in columns 6 and 7. The variations in the visibility of the aurora are thus shown to lag behind the variations in solar activity in the 36-year period by about 10 or 15 years. This probably indicates a dependence upon terrestrial as well as solar conditions. The belt of maximum frequency of auroras descends to lower latitudes during increasing solar activity in the 11-year and the 36-year cycles. It was shown in the first part of this paper that a similar change of position occurs in the belt of maximum storm-frequency during cold periods, which will be shown to follow closely periods of maximum solar activity. The intimate relation between auroral and meteorological phenomena is thus apparent.

Correlation of solar and terrestrial variations.—As shown above, terrestrial and solar phenomena undergo cyclical variations in recurring intervals of about 36 years, and these variations have been traced back to about 1050 A. D. in each instance. The epochs of maximum and minimum severity of winters, Table I, series 9, which are practically coincident with those of temperature, will be considered as the primary series of meteorological epochs. Comparing these epochs with those of solar activity, Table II, columns 6 and 7, it is readily apparent that the two series synchronize closely, with an average retardation of about 7 years in the meteorological epochs.

When the two series of epochs, previous to 1610, are compared, the synchronism is less exact, as might be expected. It seems remarkable that from the epochs of sun-spot maxima, determined by Fritz, the epochs of the 36-year cycle should be derived in such a regular sequence, considering the source and character of the data he utilized. Although the lag of the meteorological epochs is somewhat greater and more variable than that since 1610, still the correspondence is much closer than one would anticipate. The great number of coincidences shown in the comparison of the two series of epochs from 1050 to 1895 makes the conclusion irresistible that our meteoro-

logical variations are conditioned upon variations in solar activity. (Compare Chart 2.)

It was stated above that the epochs of maximum and minimum spottedness in the 36-year cycle show a slight retardation when compared with the epochs with which the meteorological epochs were compared. Hence the latter differ by less than 5 years from the epochs of variation of solar spottedness.

Summarizing, therefore, the foregoing results, we conclude that periods of maximum solar activity, characterized by a minimum length of the 11-year cycle, are followed 7 to 10 years later by terrestrial temperature minima, and 6 years thereafter by rainfall maxima; and that, coincidently with the low temperature, the activity of the general circulation reaches a maximum, and storm-centers move with increased velocity and in lower latitudes.

III. SHORT CYCLES OF SOLAR AND METEOROLOGICAL PHENOMENA

A brief reference will now be made to the shorter cycles of solar activity and the corresponding meteorological variations.

The evidence for the existence of an 11-year variation in meteorological phenomena is very conflicting and inconclusive, but on the whole it points to greater activity of atmospheric circulation, lower temperature, and excessive precipitation shortly after the sun-spot maximum.

A study of the short cycle of solar activity, evidenced by variations in the frequency of solar prominences, yields far more satisfactory results. Sir Norman Lockyer and Dr. W. J. S. Lockyer[1] first announced a period of about $3\frac{1}{2}$ years in the prominence frequency, and traced synchronous variations in pressure and rainfall. Professor F. H. Bigelow[2] previously had shown that a 3-year variation existed in meteorological phenomena in the United States and found similar fluctuations in the terrestrial magnetic field. In a recent paper[3] he showed that the pressure over the Indo-Oceanic and

[1] "On Some Phenomena which Suggest a Short Period of Solar and Meteorological Changes," *Proc. R. S.*, **70**, 500, June, 1902.

[2] "Inversion of Temperatures in the 26.68-Day Solar Magnetic Period," *Am. Jour. Science* (4), **18**, Dec., 1894.

[3] "Synchronism of the Variations of the Solar Prominences with the Terrestrial Barometric Pressures and the Temperatures," *Monthly Weather Review*, **31**, 509, 1903.

Arctic regions varies directly with the prominence frequency, while over the Azores and Hawaii it varies inversely; also that the temperature over Iceland, northern Europe, and the northern United States varies inversely with the prominence frequency

In order to trace synchronous variations in the $3\frac{1}{2}$-year cycle, analogous to those shown above to exist in the 36-year cycle, I have made a careful comparison of the variations in the prominence frequency with those of various meteorological phenomena during the period 1873–1903, and the following conclusions appear to be justified. Coinciding with the maxima of the prominence curve, indicating secondary maxima of solar activity, are:

1. Increased activity of atmospheric circulation, shown by—
   a) Greater velocity of storm movement in longitude.
   b) Lower latitude of storm-tracks.
2. Higher pressure over arctic and tropical regions.
3. Lower pressure over middle latitudes, shown most clearly by the pressure at the Azores and Hawaii.
4. Weaker gradient between the Azores and Iceland.
5. Lower temperature in Iceland, northern Europe, and the northern United States.

These conditions, prevailing at or shortly after the secondary maxima of solar activity in the $3\frac{1}{2}$-year cycle are identical with those shown to exist in connection with the solar maxima of the 36-year cycle, and the two results are mutually confirmatory.

The effect of an increase in solar activity upon the Earth's atmosphere, shown by both short- and long-period variations, is immediate, and results in increased activity of the polar whirls, forcing equatorward masses of cold air, and causing both highs and lows to traverse paths in lower latitudes and with increased velocity.

Speculation as to the manner in which the solar influence is exerted seems unprofitable in the light of our present knowledge of the manifestations of solar energy. Whether variations in solar radiation exist, sufficient to produce such variations in climate, is a problem still undetermined. The paradox involved in attributing the cold periods to diminished solar radiation, apparently precludes variations in the latter as the efficient cause, or at least renders it probable that they are of secondary importance. The fact that our meteoro-

logical variations are greater and occur earlier in high latitudes seems to indicate that the polar and not the equatorial regions are mainly influenced by the varying manifestation of solar energy, in which case some action involving variations in the magnetic field of the earth must be taken into consideration.

IV. THE THREE-HUNDRED-YEAR CYCLE

The tendency of the ratio *a:b* to decrease from about 1685 to 1860 suggests a long-period variation in solar activity, since, as shown above, this ratio varies inversely with the relative-numbers in the 36-year cycle. Furthermore, the length of the 36-year interval is not uniform, but is least about 1850, averaging 30 years, greatest during the early part of the eighteenth century, averaging 40 years, and decreases again in the early part of the seventeenth century.

Regarding variations in solar activity since 1600, the records indicate that a chief minimum occurred in the latter part of the seventeenth century and a maximum about the middle of the nineteenth century. Miss Clerke[1] writes: "Spoerer's researches showed that the law of zones was in abeyance during some 70 years previous to 1716, during which period sun-spots remained persistently scarce, and auroral displays were feeble and infrequent even in high latitudes. An unaccountable suspension of solar activity is, in fact, indicated." Young[2] writes: "From 1672 to 1704 absolutely no spots were recorded in the northern hemisphere."

Thus considering the period 1600 to 1900, a minimum of solar activity prevailed about 1680, associated with a maximum value of the ratio *a:b* and a maximum length of the 36-year interval; the reverse conditions prevailed about 1860. The maximum of 1778 and the minimum of 1810 appear to be phases of a secondary variation.

For the centuries previous to 1600 we have the catalogue of early observations of sun-spots and auroras, compiled by Fritz, which enable us to trace this secular variation back for nearly 1500 years. The following table gives for each hundred-year interval the number of years when sun-spots and auroras were recorded.

[1] *History of Astronomy*, p. 148.

[2] *The Sun*, p. 149.

Interval, A. D.	Sun-Spots	Auroras
100– 200	1	1
200– 300	1	0
300– 400	24	2
400– 500	3	8
500– 600	8	25
600– 700	1	11
700– 800	1	12
800– 900	10	19
900–1000	1	21
1000–1100	6	13
1100–1200	19	36
1200–1300	7	12
1300–1400	10	18
1400–1500	0	6
1500–1600	7	56

Curves showing this secular variation in the frequency of sun-spots and auroras may be found on Chart 3.

Fritz[1] asserts that the sixth, ninth, twelfth, sixteenth, and nineteenth centuries have been distinguished by great and frequent auroral displays; the above table of frequency of auroras in each century serves to illustrate this statement. The table of sun-spot frequency shows that sun-spots have also been more frequently observed in these centuries. It was shown above that the periods of maximum visibility of the aurora during the last 200 years have been preceded by periods of increased solar activity, and it may therefore be considered as probable that unusual outbursts of solar energy occurred during the centuries above mentioned.

Approximate epochs for these long-period variations of solar activity and auroral frequency are given in Table VI, from which the average length of this cycle is found to be about 300 years.

Since the length of the 36-year cycle has varied parallel with variations of solar activity during the last 300 years, a similar relation would be expected to prevail in the preceding centuries. The series of 36-year epochs in Table III show that variations in the length of this cycle have indeed occurred. The epochs of maxima and minima with the mean length at each epoch are given in Table VI, columns 5 and 6. These epochs correspond very well with the epochs of sun-spot and auroral maxima and minima. The conclusion is that

[1] *Die Beziehungen der Sonnenflecken zu den magnetischen und meteorologischen Erscheinungen der Erde*, p. 41.

variations in solar activity in the 300-year cycle are associated with variations in the length of the 36-year solar cycle, ranging from 30 to 45 years, the period-length decreasing with increasing solar activity. A smoothed curve of these variations in the length of the 36-year solar cycle is shown in Chart 3. Similar variations in the length of the 11-year cycle exist, and the approximate epochs of minimum and maximum length with the average interval at each epoch are shown in Table VI, columns 11 and 12.

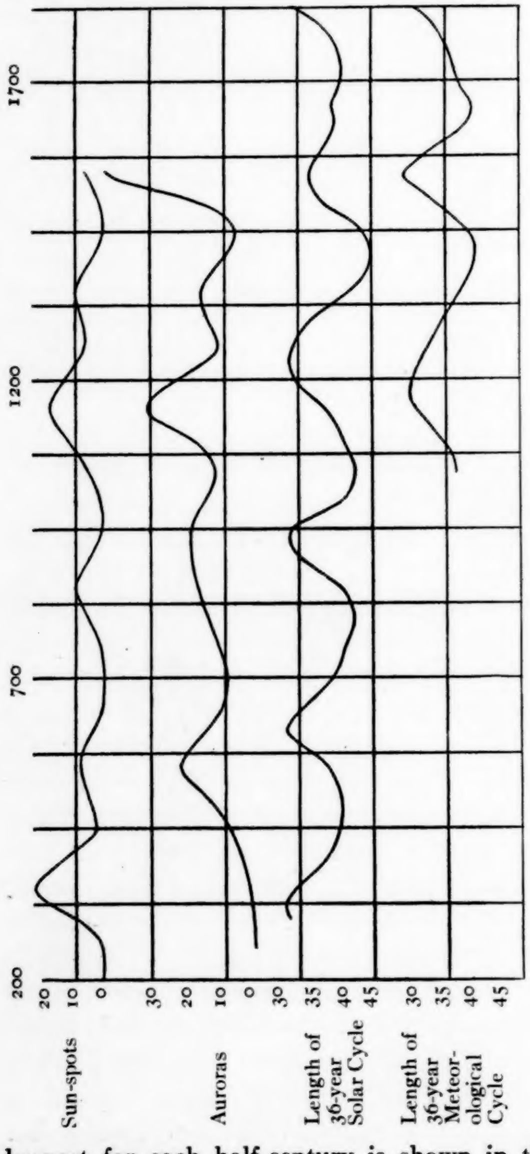


CHART 3.—The 300-Year Cycle.

With regard to meteorological variations in a cycle of 300 years, the best evidence at hand is the nearly continuous record of the time of grape harvest at Dijon, France, since 1400. The average date of beginning of the harvest for each half-century is shown in the following table:

Period	Average Date	Period	Average Date
1400–1450	September 24	1650–1700	September 23
1450–1500	September 28	1700–1750	September 27
1500–1550	September 27	1750–1800	September 30
1550–1600	September 29	1800–1850	October 2
1600–1650	September 26		

There is clear evidence of periods of high temperature about 1425 and 1675, while low temperatures prevailed about 1550 and 1825.

The average date of opening of navigation at Riga has varied as follows:

1530–1623	March 28.2	1751–1802	March 25.3
1626–1750	March 24.4	1803–1852	March 27.5

The variations in temperature shown by this table accord very well with those shown by the average time of grape harvest.

Referring to the series of epochs of the severity of winters, Table I, series 9, an inspection of columns 3 and 4 discloses variations in the length of the 36-year interval, minima occurring about 1200, 1525, and 1850, and maxima about 1050, 1415, and 1675. Chart 3 contains a smoothed curve of these variations. The secular variations in the time of grape harvest at Dijon agree closely with these variations in the length of the 36-year cycle, periods of low temperature corresponding with periods during which the average length of the cycle is 30 to 32 years, while periods of high temperature coincide with an average length of 40 to 42 years.

These epochs of maxima and minima in the length of the 36-year cycle in meteorological phenomena correspond closely with those found above for the 36-year solar cycle, thus furnishing additional evidence of a close connection between the two phenomena.

Chart 2 exhibits graphically this 300-year variation in the length of the 36-year solar and meteorological cycles.

NOTE.—The increased retardation of the meteorological epochs at the minima of the 300-year solar cycle, shown by these curves, is significant as indicating that the relation between the two phenomena is one of cause and effect.

TABLE I

Meteorological Epochs

1						2				3			
Temperature						Precipitation				Height of Water-Surface			
Europe		United States		Whole Earth		Europe		United States		(a) Closed Lakes		(b) Rivers	
Cold	Warm	Cold	Warm	Cold	W'rm	Wet	Dry	Wet	Dry	High	Low	High	Low
										1600			
										1638?			
											1656?		
										1674?			
											1683?		
						1701–05				1710			
							1726–30				1720		
1736–40				1738		1741–45		1740		1740		1740	
	1750				1750		1761–65		1762?		1760		1760
1766–70		1784?		1770		1771–75		1775		1780		1775	
	1786–90		1796		1790		1796–00		1795		1800		1795
1811–15		1815		1813		1811–15		1815		1820		1820	
	1821–25		1826		1825		1831–35		1836		1835		1831–35
1836–40		1837		1838		1846–50		1848		1850		1850	
	1860		1860		1860		1861–65		1864		1865		1861–65
1876–80		1880		1878		1880		1882		1880		1876–80	
	1895		1892				1898		1895				1895

4				5		6		7		8	
Barometric Pressure (a)		Pressure-Gradient (b)		Frequency of Easterly Winds		Variability of Temperature		Freq'cy of West Indian Hurricanes		Frequency of Thunderstorms	
Low	High	Min.	Max.	Max.	Min.	Max.	Min.	Max.	Min.	Min.	Max.
								1590?			
								1625?			
								1655			
									1685		
								1710			
									1725		
1741–45								1745			
	1760				1755		1755		1762		1768
1771–75				1775		1780		1786		1783	
	1795		1790		1790		1795		1798		1797
1811–15		1815		1815		1810		1817		1814	
	1831–35		1831–35		1830		1821–25		1823		1822
1846–50		1840		1845		1836–40		1838		1837	
	1861–65		1860		1865		1855		1864		1852
1876–80		1875		1880		1876–80		1885			
	1895		1895		1895		1895		1895		

TABLE I—*Continued*

9				10		11		12	
Frequency of Severe Winters				Season of Navigation		Time of Grape Harvest		Grain Prices	
		Interval of Three Periods							
Max. or Cold	Min. or Warm	Max. to Max.	Min. to Min.	Short	Long	Late	Early	High	Low
1000									
	1025								
1045									
	1060	120							
1075			110						
	1095	105							
1120			110						
	1135	105							
1150			100						
	1170	95							
1180			100						
	1195	100							
1215			90						
	1235	100							
1250			105						
	1260	100							1265
1280			105					1290	
	1300	110							1305
1315			115					1320	
	1340	115							1340
1360			115					1370	
	1375	120							1385
1395			120			1405		1405	
	1415	125					1421–25		1420
1435			125			1446–50		1438	
	1460	120					1466–70		1465
1485			115			1481–85		1482	
	1500	110					1501–05		1500
1515			95			1511–15		1527	
	1530	95					1526–30		1540
1545			90	1560		1545		1555	
	1555	100			1570		1556–60		1570
1580			105	1591–95		1585		1596	
	1590	110			1611–15		1601–05		1603
1615			125	1621–25		1621–25		1640	
	1635	120			1645		1636–40		1654
1655			125	1660		1660		1662	
	1680	120			1690		1681–85		1688
1700			120	1710		1701–05		1700	
	1715	120			1726–30		1726–30		1730
1735			110	1741–45		1741–45		1740	
	1755	115			1761–65		1756–60		1753
1775			110	1781–85		1766–70		1772	
	1790	105			1791–95		1786–90		1785
1815			105	1811–15		1815		1812	
	1825	100			1821–25		1831–35		1835
1840			100	1841–45		1846–50		1855	
	1860				1861–65		1865		1864
1875				1876–80		1881–85		1873	
	1890								1895
1910?									

TABLE II

SUN-SPOT EPOCHS (WOLFER)

Epochs of 11-Year Cycle		Interval			Epochs of 36-Year Cycle		Relative-Numbers		Interval		Ratio	
Max.	Min.	Max. to Max.	Min. to Min.	Smooth'd Means	Max.	Min.	At Maxima	Av'ge Min. to Min.	Min. to Max. a	Max. to Min. b	$a:b$	$a:b$ Smooth'd
1	2	3	4	5	6	7	8	9	10	11	12	13
	1610.8											
1615.5			8.2	9.4	1615				4.7		1.34	
	1619.0	10.5		11.2						3.5		
1626.0			15.0	13.0					7.0		0.87	
	1634.0	13.5		13.2		1630				8.0		
1639.5			11.0	11.3					5.5		1.00	0.94
	1645.0	9.5		10.2						5.5		
1649.0			10.0	10.2	1647				4.0		0.66	1.07
	1655.0	11.0		10.7						6.0		
1660.0			11.0	12.3					5.0		0.83	1.14
	1666.0	15.0		13.2		1670				6.0		
1675.0			13.5	12.8					9.0		2.00	1.08
	1679.5	10.0		11.2						4.5		
1685.0			10.0	9.3			67		5.5		1.22	1.18
	1689.5	8.0		8.8	1690					4.5		
1693.0			8.5	9.7			68		3.5		0.70	1.25
	1698.0	12.5		11.7						5.0		
1705.5			14.0	13.1		1707	50	17	7.5		1.15	0.97
	1712.0	12.7		12.7						6.5		
1718.2			11.5	11.2			67	27	6.2		1.17	0.87
	1723.5	9.3		10.4						5.3		
1727.5			10.5	10.3	1725		92	43	4.0		0.61	0.95
	1734.0	11.2		10.9						6.5		
1738.7			11.0	11.3			88	41	4.7		0.74	0.97
	1745.0	11.6		10.9		1745				6.3		
1750.3			10.2	11.0			68	33	5.3		1.08	0.85
	1755.2	11.2		10.9						4.9		
1761.5			11.3	10.2			86	52	6.3		1.26	0.82
	1766.5	8.2		9.5						5.0		
1769.7			9.0	8.6	1770		116	63	3.2		0.55	0.74
	1775.5	8.7		9.0						5.8		
1778.4			9.2	9.2			158	69	2.9		0.46	0.78
	1784.7	9.7		10.8						6.3		
1788.1			13.6	13.5		1790	141	50	3.4		0.33	0.69
	1798.3	17.1		14.3						10.2		
1805.2			12.3	13.5	1807		49	30	6.9		1.28	0.91
	1810.6	11.2		12.1						5.4		
1816.4			12.7	12.5			49	19	5.8		0.84	0.92
	1823.3	13.5		12.3		1820				6.9		
1829.9			10.6	10.5			72	40	6.6		1.65	0.97
	1833.9	7.3		9.2	1835					4.0		
1837.2			9.6	9.3			147	65	3.3		0.52	0.83
	1843.5	10.9		11.0						6.3		
1848.1			12.5	11.8			132	52	4.6		0.58	0.75
	1856.0	12.0		11.9		1853				7.9		
1860.1			11.2	11.2			98	50	4.1		0.58	0.59
	1867.2	10.5		11.1	1865					7.1		
1870.6			11.7	11.8			140	57	3.4		0.41	0.61
	1878.9	13.3		11.9						8.3		
1883.9			10.7	11.4		1880	75	32	5.0		0.88	
	1889.6	10.2		11.0						5.7		
1894.1			12.1				88	36	4.5		0.61	
	1901.7									7.6		

TABLE III

EPOCHS OF SUN-SPOT MAXIMA (FRITZ)

EPOCHS OF MAXIMA	INTERVAL MAX. TO MAX.	EPOCHS OF 36-YEAR CYCLE		EPOCHS OF MAXIMA	INTERVAL MAX. TO MAX.	EPOCHS OF 36-YEAR CYCLE	
		Max.	Min.			Max.	Min.
(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
1057		1060		1324			
	12				10		
1069				1334		1335	
	12				14		
1081			1080	1348			
	15				12		1360
1096				1360			
	8	1100			12		
1104				1372			
	13				8		
1117			1120	1380		1380	
	13				8		
1130				1388			
	8				13		
1138		1140		1401			1405
	10				14		
1148				1415*			
	13				10		
1161			1160	1425*		1425	
	16				10		
1177				1435			
	8	1180			13		
1185				1448*			1450
	8				14		
1193				1462			
	10		1195		10		
1203				1472		1470	
	9	1205			11		
1212*				1483			
	13				16		1490
1225			1225	1499*			
	13				12		
1238		1240		1511		1510	
	9				7		
1247				1518			
	13		1255		11		1525
1260				1529			
	10				9		
1270		1270		1538		1540	
	8				11		
1278				1549			
	13		1285		11		1555
1291				1560			
	9				12		
1300*		1300		1572			
	8				8	1575	
1308				1580			
	16		1320		11		
1324				1501			1590
					14		
				1605			

TABLE III—*Continued*

APPROXIMATE EPOCHS OF THIRTY-SIX-YEAR SOLAR CYCLE, 295 A. D. TO 1100 A. D

Maxima	Minima	Maxima	Minima	Maxima	Minima
295	315	585	570	845	865
325	345	615	600	880	900
355	375	645	630	915	930
390	415	680	665	045	960
430	455	720	700	975	995
470	490	760	740	1015	1040
510	530	800	780	1060	1080
550			825	1100	

TABLE IV

EPOCHS OF MAGNETIC DECLINATION RANGE (FRITZ)

Epochs		Interval			Epochs of 36-Year Cycle		Average Range at Epochs	
Maximum	Minimum	Max. to Max.	Min. to Min.	Smoothed Means	Max.	Min.	Max.	Min.
1	2	3	4	5	6	7	8	9
1778.0							14.5	
	1784.8	9.4						9.8
1787.4			15.6	13.7		1792	15.1	
	1800.4	16.1		14.4+				7.0
1803.5			11.5	13.7	1805		9.2	
	1811.9	13.6		12.5−				6.6
1817.1			12.3	12.9+		1820	9.2	
	1824.2	12.8		11.8				6.6
1829.9			10.4	10.1			12.4	
	1834.6	7.0		9.1−	1835			9.2
1836.9			9.8	9.3			14.1	
	1844.4	11.2		11.3				8.6
1848.1			12.9	12.2+		1852	12.5	
	1857.3	12.6		11.9				6.5
1860.7			10.2	11.0			11.4	
	1867.5	10.2		10.5−	1864			7.9
1870.9			11.0	11.4			12.8	
	1878.5	13.0		11.8+				6.7
1883.9			11.3	11.4		1880		
	1889.8	9.9						
1893.8								

TABLE V

EPOCHS OF AURORAL FREQUENCY (FRITZ)

Epochs		Interval			Epochs of 36-Year Cycle		Epochs of Visibility	
Max.	Min.	Max. to Max.	Min. to Min.	Smoothed Means	Max.	Min.	Max.	Min.
1	2	3	4	5	6	7	8	9
1692								
	1700	15.4						
1707.4			12.4	13.4+		1700		
	1712.4	12.3		12.1				1710
1719.7			11.6	11.4				
	1724.0	10.4		10.3				
1730.1			8.8	9.1−	1730			
	1732.8	8.2		9.6				
1738.3			11.8	10.2			1738	
	1744.6	10.5		10.7				
1748.8			9.8	10.4				
	1754.4	10.8		10.4				
1759.6			10.7	11.5+		1760		
	1765.1	13.1		11.6				1765
1772.7			11.1	10.6				
	1776.2	7.6		8.3				
1780.3			6.2	7.1−	1780			
	1782.4	7.6		10.1				
1787.9			16.4	13.6			1788	
	1798.8	16.8		15.1+		1800		
1804.7			12.1	14.2				
	1810.9	13.7		12.4				1810
1818.4			11.3	12.1				
	1822.2	11.2		11.5				
1829.6			12.1	11.3				
	1834.3	10.7		10.8				
1840.3			9.6	10.0−	1840			
	1843.9	9.6		10.5				
1849.9			12.4	10.9			1848	
	1856.3	10.7		11.0+		1855		
1860.6			10.0	10.2				1860
	1866.3	9.9		10.7	1865			
1870.5			12.2	11.9			1870	
	1878.5	13.5						
1883.5								

TABLE VI

EPOCHS OF THE THREE-HUNDRED-YEAR CYCLE

Solar Spottedness		Auroral Frequency		Length of 36-Year Cycle				Temperature Shown by Time of Grape Harvest		Length of 11-Year Cycle	
				Solar		Meteorological					
Max.	Min.	Max.	Min.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	2	3	4	5	6	7	8	9	10	11	12
350				325–30						325–10.40	
	450				475–39						440–11.55
550		575		600–30						575–10.20	
	700		750		800–42						750–11.40
850		900		925–30						975–10.37	
	1000		1050		1050–42		1050–40				1100–11.73
1150		1175		1225–31		1200–32				1225–10.50	
	1450		1450		1410–45		1415–41		1425		1450–11.90
1550		1550		1550–32		1525–32		1550		1550–10.63	
	1680		1700		1700–41		1675–41		1675		1650–11.37
1850		1860		1850–30		1850–32		1825		1750–10.55	

WASHINGTON, D. C.,
December, 1904.

AN ELEMENTARY DISCUSSION OF THE ACTION OF A PRISM ON WHITE LIGHT

By J. S. AMES

It is generally recognized at the present time that white light, so called, is not due to the superposition of regular trains of waves, but to irregular disturbances or "pulses." When such light, however, is dispersed by a grating or prism, it is resolved into components which have a certain periodicity impressed upon them. How closely this periodic phenomenon resembles homogeneous waves has been discussed by Gouy and others. From this point of view the observed periodicity is not innate in the incident white light, but is directly caused by the grating or prism. An infinitely thin pulse will be spread out by the dispersive mechanism into an extended disturbance in which there are periodicities.

Only a word need be said in regard to the action of the grating on white light, because the matter has been discussed so fully by Schuster in a paper in the *Philosophical Magazine* for June 1894, (5) **37**, 509, entitled "On Interference Phenomena." In a later paper[1] on "Talbot's Bands" Schuster again outlines the theory; and in his book, *The Theory of Optics* (London, 1904), he also discusses the same subject. The simplest case to consider is that of a single thin plane pulse falling normally on a plane reflecting grating. Let us assume that the grating consists of reflecting and non-reflecting strips, parallel and evenly spaced, and that the *only action of the grating* is to produce reversed cylindrical pulses at its reflecting strips. These pulses will be reflected back by the strips; and if the grating be viewed from any angle, a series of regularly spaced pulses will enter the eye or telescope. Thus, if the parallel lines A_1M_1, A_2M_2, etc., are drawn, making any angle, θ, with the normal to the grating, and if a line A_1A_2 be drawn perpendicular to these lines, a pulse will reach A_1 a definite interval of time before one reaches A_2, and in turn the pulse reaches A_2 by the same interval

[1] *Phil. Mag.*, (6) **7**, 1, Jan. 1904.

of time ahead of the pulse reaching A_3, etc. If a is the grating space, and V the velocity of the pulses, this definite interval of time is $(a \sin \theta)/V$. The quantity $a \sin \theta$ marks, therefore, the periodicity imparted to the pulse by the grating for an observer viewing the grating from the angle θ. These "rays" $M_1 A_1$, $M_2 A_2$, etc., may be regarded as meeting at infinity, or as being brought to a focus by a converging lens. If the latter is the case, there will be a periodic phenomenon at the focus, with the period $a \sin \theta/V$, which will persist until all the spherical pulses produced by the single incident plane pulse have passed by; that is, until N pulses have passed,

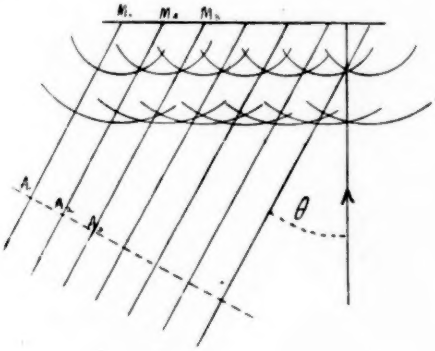


FIG. 1

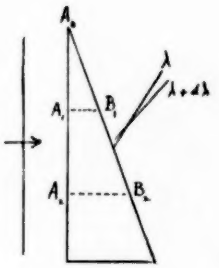


FIG. 2

if N is the number of reflecting strips of the grating. Since the "resolving power" of a grating is a measure of its efficiency in distinguishing between periodicities which are nearly equal, it is evident why this is fixed by the number of lines in the grating, as it is. On the assumption made above in regard to the action of the grating, all the light would be dispersed into two first-order spectra, one on each side of the normal. The fact that this is not true in practice, but that there are series of spectra of different orders is explained by analyzing the true action of the grating, as has been done by Rayleigh and by Schuster.

The explanation of the process by which a prism imparts periodicity to white light is by no means as self-evident as is that just given for a grating. Larmor in his *Æther and Matter*, p. 239, gives a most artificial solution, which does not appeal to one's feeling that a simple elementary explanation is possible. Schuster in the

Philosophical Magazine for January 1904, and again in his *Optics*, outlines a solution which apparently was given in full before the British Association meeting of 1903. What follows in this note may be identical with Schuster's British Association paper, but as the writer has no knowledge of this, and has not seen it in print, it may not be repetition, especially as the considerations brought forward in this discusison and all the formulæ are entirely independent of the papers mentioned.

The simplest type of pulse that one may treat mathematically is a so-called "group" consisting of two homogeneous trains of waves, of the same amplitude, but different velocity, and of slightly different wave-length. Such a group is defined by the equation:

$$y=\cos\frac{2\pi}{\lambda}(x-Vt)+\cos\frac{2\pi}{\lambda^1}(x-V^1t)\ ,$$

where

$$\lambda^1=\lambda+d\lambda$$

and

$$V^1=V+\frac{dV}{d\lambda}d\lambda\ .$$

By ordinary trigonometrical transformation this becomes

$$y=2\cos\pi\left[x\left(\frac{1}{\lambda}+\frac{1}{\lambda^1}\right)-t\left(\frac{V}{\lambda}+\frac{V^1}{\lambda^1}\right)\right].\cos\pi\left[x\left(\frac{1}{\lambda}-\frac{1}{\lambda^1}\right)-t\left(\frac{V}{\lambda}-\frac{V^1}{\lambda^1}\right)\right]$$

$$=2\cos\frac{2\pi}{\lambda}(x-Vt).\cos\pi\frac{d\lambda}{\lambda^2}\left[x-\left(V-\lambda\frac{dV}{d\lambda}\right)t\right]\ ,$$

which gives a physical idea of the appearance of the group. The most important property of such a group is at once apparent, viz., a group does not advance as such, keeping its identity, but, on the contrary, continuously changes its nature as one train of waves gains on the other.[1] If, however, the appearance of the group at any point is noted at any instant, that same character will reappear at a later time in a position displaced in the direction of advance of the waves or, in certain cases, displaced backwards.

The time, T, required for the group to reappear, i. e., the "period" of the group, is $1/\frac{dV}{d\lambda}$, as follows at once from the consideration

[1] The only places in print in which attention has been called to this fact, so far as is known to the writer, are in the recent papers of Schuster.

that in this time one train of waves mus have gained a distance equal to the difference in wave-length; in symbols

$$T(V^1-V)=\lambda^1-\lambda$$

or

$$T\frac{dV}{d\lambda}=1\ .$$

Similarly, the distance X between the points at which any one feature of the group is restored must be such that

$$VT=X+\lambda,$$

or

$$X=\left(V-\lambda\frac{dV}{d\lambda}\right)T\ .$$

We may call the ratio $\frac{X}{T}$ the "velocity" of the group; that is, $U\equiv V-\lambda\frac{dV}{d\lambda}$. It follows, then, that $X=\lambda U/(V-U)$.

Applying the above statements to the theory of light, it is evident that a group in the pure ether advances preserving its identity, because $V^1=V$; but when it enters a dispersive medium, its character proceeds to undergo periodic changes, reversing, reappearing, etc., as would be noted by an observer advancing with the "group velocity." Let us consider the action of a prism upon such a group, and for the sake of simplicity let the group have a plane front and fall perpendicularly upon the face of the prism. We may choose any feature of the group by which to recognize it and note its periodic recurrence, e. g., the condition marked by the sum of the two amplitudes of the component trains. As the group advances toward the prism, this "crest" moves forward with the velocity V_e, that of waves in the pure ether; when the group enters the prism, it changes its form, the "crest" recurring at intervals equal to X; consequently at certain points B_1, B_2, etc., on the second face of the prism, such that $A_1B_1=X$, $A_2B_2=2X$, etc., the "crest" will emerge. Thus the vertex A_0, and the points B_1, B_2, etc., may serve as centers of secondary disturbances in a Huygens' construction, and a plane drawn tangent to these secondary spheres may be called the "group-front." It is apparent, however, that in the time T required for the "crest" to reappear at B_1 after disappearance at A_1 the component *trains of waves* have advanced a greater distance than A_1B_1, and have emerged

from the prism and passed on as two separate trains in slightly different directions, owing to their different indices of refraction.

There is thus a periodicity in the group-front, due to the fact that at certain regularly spaced intervals there is the maximum amplitude. This is caused obviously by the superposition of the two crests of the component *trains of waves* whose wave-fronts cross at a small angle. We can therefore study the direction of advance of any one "crest" in the group-front, and at the same time calculate the periodicity produced when the group is received by a telescope, by plotting the traces of the two trains of waves.

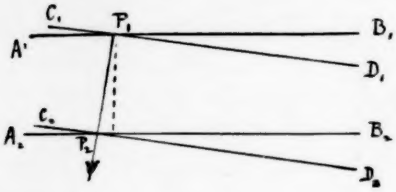


FIG. 3

Let the lines A_1B_1 and C_1D_1 be the traces of the crests of the two trains of waves at any instant, P_1, their point of intersection will then be a "crest" of the group-front; at a certain time later the two wave-crests will have advanced through equal distances to positions A_2B_2 and C_2D_2, and their point of intersection, P_2, will mark the new position of the "crest" of the group-front. In other words, P_1P_2, a line perpendicular to the bisector of the angle between A_1B_1 and C_1D_1, may be called the direction of advance of the group; that is, the receiving telescope must have this direction.

To deduce the periodicity observed by the telescope, one has but to draw the crests of the two trains of waves as they are at any instant, for a distance of several wave-lengths.

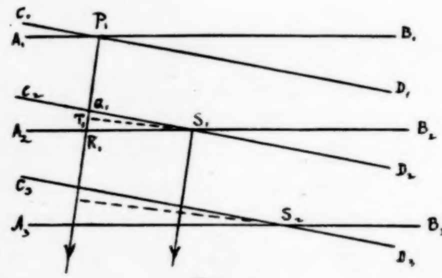


FIG. 4

Thus, let A_1B_1, A_2B_2, A_3B_3, etc., be the traces *at any one instant* of the wave-crests of the train whose wave-length in the pure ether is $\lambda_e + d\lambda_e$; let C_1D_1, C_2D_2, C_3D_3, etc., be those of the train whose wave-length is λ_e, *at the same instant;* and let P_1, S_1, S_2, etc., be their points of intersection. As the trains *advance,* the "crest" P_1 moves, as has just been shown, in the direction $P_1Q_1R_1$; the "crest" S_1 moves in a parallel

direction, etc. Consequently, the periodicity observed by the telescope is given by the distance P_1T_1, where T_1 is the foot of the perpendicular dropped from S_1 upon $P_1Q_1R_1$. If the angle between A_1B_1 and C_1D_1 is called a, this periodic distance $P_1T_1 = \frac{1}{\cos\frac{a}{2}}\left(\lambda_e + \frac{d\lambda_e}{2}\right)$; and therefore in the limit equals λ_e.

The case of a more complicated group or of a pulse is, to a certain extent, equally simple. Any group or pulse may be analyzed into a number of simple groups like those discussed above, each such

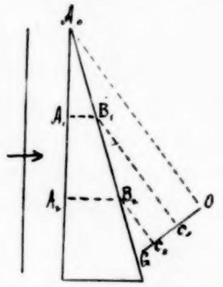


FIG. 5

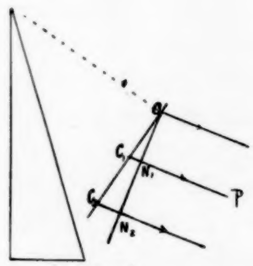


FIG. 6

group being "associated" with a certain train of waves of wave-length λ. If such a complex group enters a dispersive medium, two things must be noted: (1) Since the velocity of any simple group is $V - \lambda\frac{dV}{d\lambda}$, the different component groups will have different velocities, and so their group-fronts will be differently refracted, both on entering and on emerging; (2) since the distance required for a certain feature of a group to reappear, i. e., the length X, is different for the different groups, they will recur at different intervals, and therefore the complex group itself could not reappear. These complications might be avoided if a dispersive medium could be found for which $V - \lambda\frac{dV}{d\lambda}$ and $\left(V - \lambda\frac{dV}{d\lambda}\right)\frac{1}{\frac{dV}{d\lambda}}$ are both constant. These conditions are satisfied if the dispersion formula for the medium obeys the relation $V = A + B\lambda$, where A and B are constants; for, in this case, the group-velocity is A, and the periodic distance X is A/B; both of which are independent of λ, and therefore the same for all the component simple groups.

To avoid any refraction of the *wave-fronts* of the ultimate trains of waves on entrance into a prism, we may, as before, consider normal incidence. Then, again, we will have what may be called a "group-front" for the emerging light by drawing a plane tangent to secondary spherical disturbances having A_0, B_1, B_2, etc., as centers, where $A_1B_1=X$, $A_2B_2=2X$, etc. Let the trace of this plane be OG. It will contain periodicities, for the conditions are the same at O, C_1, C_2, etc., the points of tangency. As is seen by considering the complex group made up of simple ones, the condition at these points is due to a superposition of trains of waves, and, as these advance, the different component simple groups separate out and give rise to different periodicities proceeding in different directions. We may trace these in the following manner: Let OC_1C_2 . . . . be the "group-front;" then the effects propagated in the direction C_1P—which is taken at random—have the periodicity C_1N_1 where the line ON_1N_2 . . . . . is drawn perpendicular to the direction C_1P; for $C_2N_2=2C_1N_1$, etc. We will prove that this periodic distance C_1N_1 is equal to λ_e, where this is the wave-length of the *train of waves* which, after normal incidence on the prism, would on emergence have the *wave-front* ON_1N_2. . . . . . The difference in time required for the group-front and the train of waves to traverse the prism along the line A_1B_1 is

$$X\left(\frac{1}{U}-\frac{1}{V}\right) \quad \text{or} \quad X\frac{V-U}{UV} \ ,$$

which, as proved above, equals $\frac{\lambda}{V}$, where λ is the wave-length of the train of waves while in the prism. Hence the distance of the wave-front in advance of the group-front, after emergence, along the line C_1P is $\frac{V_e\lambda}{V}$ or $\mu\lambda$, which equals λ_e. That is, the distance C_1N_1 equals λ_e.

It is thus seen that if a telescope is pointed in different directions toward the prism, disturbances of different periodicities will be brought to a focus; and, further, that the periodicity corresponding to any one direction is exactly that of the train of waves which would be brought to a focus if this train had been incident upon the prism instead of the group. In other words, a complex group gives rise,

through the agency of the prism, to periodic effects advancing in different directions, which are identical—with an important limitation, to be noted presently—with the effects which would have been produced if a complex train of waves had been incident upon the prism. Accordingly, the fact that a prism produces approximately homogeneous trains of waves when white light falls upon it is not a proof of the existence in the white light of periodic component trains of waves. The "resolving power" of the prism is evidently proportional to the number of periodicities which occur in the emergent "group-front," and, if Δ is the thickness of the base of the prism, this number equals $\frac{\Delta}{X}$ or $\frac{\Delta}{U}\frac{dV}{d\lambda}$. This limits, then, the periodic nature of the resolved components.

In thus explaining how an arbitrary group or pulse may, by means of a prism, produce what to a certain extent may be called trains of waves, a particular kind of dispersive medium has been considered. This is, however, no limitation upon the argument.

For those interested in the discussion of the nature of white light, a list of the most important papers on the subject is added:

SCHUSTER: "On Interference Phenomena." *Phil. Mag.*, (5) **37**, 509, 1894. "A Simple Explanation of Talbot's Bands." *Phil. Mag.*, (6) **7**, 1, 1904. *Boltzmann's Festschrift*, p. 569. *The Theory of Optics*, London, 1904, Chapter. XIV. Also *Phil. Mag.* (6) **5**, 344, 1903; *Nature*, **53**, 268, 1895-6; *Cam. Phil. Trans.*, **18**, 108, 1899.

RAYLEIGH: "Wave Theory of Light." *Ency. Brit.*, **24**, 1888. *Collected Works*, III, p. 47. "On the Character of the Complete Radiation at a Given Temperature." *Collected Works*, III, p. 268. *Phil. Mag.*, (5) **27**, 460, 1889. Also *Nature*, **57**, 607, 1898; *Phil. Mag.* (6) **5**, 238, 1903.

LARMOR: *Æther and Matter*. Cambridge, 1900, pp. 239, 247.

PLANCK: "Ueber die Natur des Weissen Lichtes." *Annalen der Physik*, (4) **7**, 390, 1902.

GOUY: "Sur le Mouvement Lumineux." *Journal de Physique*, (2) **5**, 354, 1886.

See also GARBASSO: *Journal de Physique*, **7**, 252 and 346, 1898.

STONEY, G. JOHNSTONE: *Phil. Mag.* **45**, 535, 1898; **46**, 253, 1898.

CARVALLO: *Journal de Physique* (3), **9**, 136, 1900.

CORBINO: *Ibid.* (4), **1**, 512, 1902, and papers in the *Comptes Rendus:* **120**, 757, 1895, by Poincare; **130**, 79, 401, 1900, by Carvallo; **130**, 238, 1900, by Fabry; **130**, 241, 560, 1900, by Gouy; **133**, 412, 1901, by Corbino.

JOHNS HOPKINS UNIVERSITY,
Baltimore, April 1905.

THE VARIABLE RADIAL VELOCITY OF γ *GEMINORUM*

BY V. M. SLIPHER

The spectrum of γ *Geminorum* is the same as that of *Sirius*. As it contains many sharp metallic lines, the radial velocity of the star can be quite accurately observed. The variability of the star's velocity was announced by Campbell in *Lick Observatory Bulletin* No. 70 and in the *Astrophysical Journal* for March 1905. I had secured, with the Lowell spectrograph, two observations:

1902, October 15: Velocity = −22 km,
1903, November 24: Velocity = − 1 km,

which showed clearly variable velocity, and the binary character of the star was awaiting announcement here at the time it was published by the Lick observers.

The publication of the Lick observations encouraged me to make more spectrograms with the hope of being able to determine the star's orbital period. To this end, Professor Frost has very kindly communicated to me the observations of the star, made at the Yerkes Observatory by himself and Mr. Adams.[1] In the accompanying table are given, in chronological order all the velocity determinations available, beginning with the early ones by Vogel and Scheiner at Potsdam.[2]

Except Vogel's measures on the first two plates, the Potsdam velocities depend upon measures of the displacement of the $H\gamma$ line, which is not suited to accurate measurement, and the determinations are therefore not comparable in accuracy with the more recent ones made elsewhere, which depend upon measures of the sharp metallic lines. It might be well to note in passing that the agreement between Vogel's and Scheiner's measures of the same plate is in reality not so satisfactory as given above, for the values here have received Vogel's

[1] Three of these observations were referred to in *Astrophysical Journal*, **15**, 217, 1902, but have not been previously published.

[2] *Publicationen des Astrophysikalischen Observatoriums zu Potsdam*, **7**, Theil I.

TABLE I

Observatory	Date	Velocity	Measurer	Remarks
Potsdam......	1888, Dec. 14	−18.1 km	Vogel	
		−19.0	Scheiner	
"	1889, Jan. 6	−14.2	Vogel	
		− 9.9	Scheiner	
"	1890, Apr. 5	−17.3	Vogel	
		−18.2	Scheiner	
"	1891, Feb. 7	−12.0	Vogel	
		− 8.1	Scheiner	
Lick.........	1899, Sept. 21	−17	Campbell	Approx. measures
		−15.4	Burns	Definitive measures
"	1899, Oct. 24	−17	Campbell	Approx. measures
		−15.1	Burns	Definitive measures
Yerkes.......	1901, Nov. 15	−15.4	Adams	Photo'd by Frost
"	1901, Nov. 20	−14.9	Adams	Photo'd by Adams
"	1901, Nov. 27	−16.4	Adams	Photo'd by Frost
Lowell........	1902, Oct. 15	−22.5	Slipher	
"	1903, Nov. 24	− 0.8	Slipher	Comparison weak
Lick.........	1904, Jan. 27	− 4.7	Burns	
Yerkes.......	1904, Dec. 6	− 8.7	Frost	Photo'd by Frost
Lick.........	1905, Feb. 13	−10.4	Burns	
Lowell........	1905, Mar. 10	−11	Slipher	Underexposed
"	1905, Mar. 20	−12	Slipher	Underexposed
"	1905, Apr. 6	−11	Slipher	
"	1905, Apr. 13	−11.8	Slipher	

empirical correction, which decreases his negative velocity by 0.9 km, and increases Scheiner's by 2.8 km; i. e., for example, the actual disagreement of the second and fourth plates was about 8 km. And, contrary to my hopes, I could not derive much assistance from the Potsdam velocities in determining the period.

To take up the later observations. Those of the Lick and the Yerkes made from 1899 to the end of 1901 gave no evidence of variation, but agreed closely, giving a velocity of −15.5 km. The first to show variation were those by the writer in October 1902 and November 1903, which give the widest range so far observed. The Lick observation at the end of January 1904 also shows clearly the variation in the velocity, confirming my observation of a marked decrease in the negative velocity near the end of 1903 or the beginning of 1904. From this epoch down to the middle of April 1905 the negative velocity has been gradually increasing, and it is probable that the maximum will be reached near the middle of 1906. The observations seem to be satisfied with a period of about three and one-half years. However, more observations near the times of

maximum and minimum velocity are needed to determine the period with accuracy, and it is hoped that this approximate period will serve to indicate the times when observations should be made to be of most value in a final investigation of the system. It is evident that the present observational data are insufficient to justify an attempt to determine the orbital elements of the star.

A curve extended backward with this period passes fairly near the first, second, and fourth of the Potsdam observations, but about 12 km above the third one.

According to this period, the orbit would seem to be quite eccentric, for the change from maximum to minimum velocity takes place in much less time than the change from minimum to maximum.

This spectroscopic system is interesting from its length of period, which is comparable with that of the telescopic system δ *Equulei*, and is, excepting the secondary period of *Polaris*, the longest yet met with among spectroscopic binaries.

LOWELL OBSERVATORY,
May 3, 1905.

Minor Contributions and Notes

STARS HAVING PECULIAR SPECTRA[1]

An examination of the photographs of the Henry Draper Memorial has led to the discovery by Mrs. Fleming of a number of variable stars and other objects having peculiar spectra. A list of these, together with three additional stars having bright hydrogen lines to which attention was called by Mr. Edward S. King, is given in Table I. The constellation and number in the *Durchmusterung* are given in the first two columns. The approximate right ascension and declination for 1900 and the catalogue magnitude, except in the case of variable stars, are given in the third, fourth, and fifth columns. The class of spectrum and a brief description of the object are given in the sixth and seventh columns. The designations for

TABLE I

PECULIAR SPECTRA

Constellation	*DM.* No.	1900 R. A.	Dec. 1900	Mag.	Spectrum	Description
		h m	° ′			
Cassiopeia	....	0 4.3	+51 0	...	Md.	Variable. H 1166.
Cepheus	....	0 7.6	+71 32	...	Pec.	Bright lines and bands.
Cassiopeia	+49°41	0 12.2	+49 44	...	Na.	Variable. H 1167.
Phoenix	−48.313	1 10.2	−48 47	9.4	Pec.	Dark bands.
Cassiopeia	....	1 50.2	+62 49	...	Pec.	Gaseous Nebula.
Eridanus	−57.400	2 2.2	−57 37	...	Md.	Variable. H 1168.
Horologium	−43.1198	3 46.7	−43 50	8.5	Pec.	Dark bands.
Camelopardalus	+58.804	4 57.4	+58 50	6.0	B Pec.	$H\epsilon$, $H\delta$, $H\gamma$, and $H\beta$, bright.
Puppis	−22.1874	7 22.8	−22 53	6.0	B Pec.	$H\beta$ bright.
Cancer	....	9 2.2	+21 58	...	Pec.	Dark bands?
Hydra	−22.2684	9 36.7	−23 8	5.0	B Pec.	$H\beta$ bright.
Ursa Major	....	12 34.4	+59 2	...	Md.	Variable. H 1169.
Virgo	....	12 57.4	+ 5 43	...	......	Variable. H 1170.
Lupus	....	14 46.8	−46 12	...	......	Variable. H 1171.
Ophiuchus	−18.4282	16 21.2	−18 14	5.2	B Pec.	$H\epsilon$, $H\delta$, $H\gamma$, $H\beta$, bright.
Draco	....	17 53.2	+64 9	...	Pec.	Dark bands.
Cygnus	....	19 57.8	+32 18	...	Pec.	Bright lines. Type V.
Cygnus	+46.3133	20 56.4	+47 8	5.3	B Pec.	$H\zeta$, $H\epsilon$, $H\delta$, $H\gamma$, $H\beta$ bright.
Cygnus	....	21 28.7	+44 10	...	Pec.	Bright lines. Gaseous Neb.
Pegasus	+22.4508	21 51.7	+22 24	...	Na.	Variable. H 1172.
Pegasus	+20.5071	21 59.7	+20 34	8.7	Pec.	Dark bands.
Piscis Austrinus	−25.16142	22 46.7	−25 49	...	Mc.	Variable. H 1173.

[1] *Harvard College Observatory Circular* No. 98.

stars north of declination $-23°$ are taken from the *Bonn Durchmusterung*, for stars between declinations $-23°$ and $-52°$ the *Cordoba Durchmusterung* is used, and for stars south of declination $-52°$ the *Cape Photographic Durchmusterung* is used. Each of the new variables has been confirmed independently by a second observer. Additional information regarding these objects will be found in the remarks following the table. In the case of new variable stars, the right ascension is followed by the designation described in the *Annals*, **48,** 93, which gives the approximate position and also the designation described in the *Annals*, **53,** No. VII, which indicates the number in the series of variables found at Harvard. This number is also given in the table for convenience of future reference.

REMARKS

h m

0 4.3. 000451=H 1166. An examination of this star on five chart plates, taken between November 23, 1898, and December 6, 1902, shows a variation of about 2.5 magnitudes. Estimates from these plates give the approximate limits, 9.0 to 11.5.

0 7.6. This object is *N.G.C.* 40. Five bright lines or bands appear in its spectrum, λ3869, 4101, 4340, 4688, and 4861. The first band is broad, and apparently coincides with the band seen in certain gaseous nebulæ. The second, third, and fifth lines are $H\delta$, $H\gamma$, and $H\beta$. The fourth band, which is the strongest of all, has the position of the characteristic line in the spectra of the fifth type. The nebular lines near wave-length 5000 are not seen. This object may therefore be intermediate between a nebula and a fifth-type star.

0 12.2. 001249=H 1167. An examination of this star on sixteen chart plates, taken between January 3, 1890, and December 19, 1902, shows a variation of about 1.5 magnitudes. Estimates from these plates give the approximate limits, 7.5 to 9.0. Spectrum already known as fourth type.

1 10.2. This spectrum is of the same type as *C. DM.*$-47°.6614$, described in Circular No. 76.

1 50.2. Assumed to be the following and southern of two faint and difficult objects, which also appears somewhat hazy. The spectrum consists of a bright band having wave-length of about 5000. Therefore this object has been assumed to be a gaseous nebula.

2 2.2. *020257*=H 1168. An examination of this star on six chart plates, taken between July 9, 1896, and September 1, 1903, shows a variation of about 2.5 magnitudes. Estimates from these plates give the approximate limits, 7.5 to 10.0.

3 46.7. Announced as Type IV, *Astron. Nach.*, **138,** 175. The spectrum is of the same type as *C. DM.*$-47°.6614$, described in Circular No. 76. The broad, dark bands in these spectra have approximately the same wave-lengths as the bands in stars of the fourth type, Class Nd, but the intensity of the light of the spectrum between each band increases toward the violet, while in the peculiar stars the light between each band is of uniform intensity throughout.

4 57.4. Fine bright lines superposed on broad, dark bands.

7 22.8. This spectrum was marked "Peculiar" on Plate C 15655, by Mr. Edward S. King. The line $H\beta$, and three faint lines whose approximate wave-lengths are 4594, 4640, and 4727, are bright in this spectrum.

9 2.2. This object is very faint and difficult, but it appears to be of the same type as *C. DM.*$-47^\circ 6614$, described in Circular No. 76.

9 36.7. $H\beta$ narrow and bright superposed on broad, dark band.

12 34.4. 123459=H 1169. An examination of this star on ten chart plates, taken between April 11, 1890, and April 7, 1905, shows a variation of more than 2.3 magnitudes. Estimates from these plates give the approximate limits, 9.7 to < 12.

12 57.4. 125705=H 1170. Found from chart plates, while examining *RT Virginis*, which follows 11^s, $0'.2$ north. Four plates, taken between April 7, 1890, and May 7, 1898, show a variation of more than a magnitude. Estimates from these plates give the approximate limits, 10.3 to 11.5.

14 46.8. *144646*=H 1171. This star follows S *Lupi* $0^s.4$, south $12''$, and on most of the plates is a difficult object, especially when *S Lupi* is bright. It has been observed on 140 chart plates, taken between June 13, 1889, and September 4, 1901. Measures of these plates give the brightest and faintest magnitudes, 10.44 and 12.81.

16 21.2. This star is χ *Ophiuchi*. Attention was called to the peculiarity of this spectrum, "Bright line, and doubling of lines," on Plate C 15590, by Mr. Edward S. King. The presence of the bright line $H\beta$ in this spectrum was announced in the *Astron. Nach.*, **126,** 163. The photograph taken on March 14, 1905, shows $H\zeta$, $H\epsilon$, $H\delta$, $H\gamma$, and $H\beta$ as fine bright lines superposed on strong dark bands. As in other spectra of this class, the bright hydrogen lines diminish progressively in intensity, those of shortest wave-length being faintest.

17 53.2. This spectrum is of the same type as *C. DM.*$-47^\circ 6614$, described in Circular No. 76.

20 56.4. This star is f^1 *Cygni*. Attention was called to the peculiarity of this spectrum, "Bright lines" on Plate C 15177, taken on November 15, 1904, by Mr. Edward S. King. This plate shows $H\zeta$, $H\epsilon$, $H\delta$, $H\gamma$, and $H\beta$ as fine bright lines superposed on strong dark bands. These lines diminish in intensity corresponding to their relatively shorter wave-length. Other fine bright lines at approximate wave-lengths 3993, 4440, 4597, and 5009 are visible. Plate C 15203, taken on November 24, 1904, shows the bright $H\delta$, $H\gamma$, and $H\beta$. The two last named lines are on the edge of shorter wave-length of the dark lines $H\gamma$ and $H\delta$. This change seems to indicate a spectroscopic binary, one component having bright hydrogen lines.

21 28.7. This object is exceedingly faint.

21 51.7. An examination of this star on nine chart plates, taken between September 18, 1892, and October 27, 1904, shows a variation of more than a magnitude. Estimates from these plates gave the approximate limits, 8.1 to 9.4. The range from direct examination is certainly greater.

21 59.7 215122=H 1172. This spectrum is of the same type as *C. DM.*$-47^\circ 6614$, described in Circular No. 76.

22 46.7. *224625*=H 1173. An examination of this star on twenty-five chart plates, taken between July 23, 1889, and October 3, 1901, shows a variation of about 0.8 of a magnitude.

SPECTRA OF KNOWN VARIABLES

The spectra of a number of known variables have also been determined from these photographs and are given in Table II. The first column contains the designation, and the second, the name of the variable. The third column gives the class of spectrum.

TABLE II

SPECTRA OF KNOWN VARIABLES

Desig.	Name	Spectrum	Desig.	Name	Spectrum	Desig.	Name	Spectrum
004958	*W Cassiopeiae*	Mb 5 c	054974	*V Camelop.*	Md 6	093178	*Y Draconis*	Md 6
015912	*S Arietis*	Md 4	055353	*Z Aurigae*	Mb	093934	*R Leonis Min.*	Md 9
031401	*X Ceti*	Mb	060450	*X Aurigae*	Md 3	104814	*U Leonis*	Md 7
032043	*Y Persei*	Na	064030	*X Geminorum*	Md 5	122532	*T Canum Venat.*	Mc.
043065	*T Camelop.*	Pec.	071713	*V Geminorum*	Md 5	175510	*RY Herculis*	Md ?
043274	*X Camelop.*	Md 6	073508	*U Canis Min.*	Mb	*195202*	*RY Aquilae*	Md
045307	*R Orionis*	Md ?	083350	*—Ursae Major.*	Md	203816	*S Delphini*	Mc.

REMARKS

004958. The spectrum of this star is given as N ? in the "Provisional Catalogue of Variable Stars," *Annals* **48,** No. III. Plate I 32618, taken on February 10, 1905, shows the spectrum of this star as Class Mb 5 c.

032043. The spectrum of this star is given as N ? in the "Provisional Catalogue of Variable Stars," *Annals,* **48,** No. III. Plate I 32279, taken on November 7, 1904, shows the spectrum as Na, or similar to *U Hydrae.*

043065. The spectrum of this star is given as N in the "Provisional Catalogue of Variable Stars," *Annals* **48,** No. III. Plate I 32380, taken on December 1, 1904, shows that this spectrum is Peculiar. The lines $H\beta$ and a wide band about 4670 are present and dark, and the faint spectrum extends to $H\epsilon$. On a poor plate this might readily be mistaken for a fourth-type spectrum. This image was carefully compared with a chart plate, I 14129, taken on December 3, 1895.

195202. The spectrum of this star is given as Md ? in the "Provisional Catalogue of Variable Stars," *Annals* **48,** No. III. Plate B 22023, taken on October 10, 1898, shows that the spectrum is Md, having the lines $H\epsilon$, $H\delta$, and $H\gamma$ bright, and resembling *R Hydrae.*

In many, if not all, of the variable stars of long period the bright hydrogen lines are not present when the star is faint. Accordingly, stars whose spectra are given as Mb, or Mc in Table II, may later be found to have spectra of Class Md.

EDWARD C. PICKERING.

MAY 5, 1905.

A PROBABLE NEW STAR, *RS OPHIUCHI*[1]

New stars can be distinguished from variables, in many cases, only by their spectra. The usual life of a new star is marked by its sudden appearance, where no star is previously known to have existed, and a gradual

[1] *Harvard College Observatory Circular* No. 99.

fading away during which it changes into a gaseous nebula. But the New Star of 1866, *T Coronae*, had already been recorded in the Bonn *Durchmusterung*, and is still visible as a star of the tenth magnitude. The New Star of 1901, *Nova Persei*, No. 2, was shown by earlier photographs to be a very faint variable, and the New Star of 1600, *P Cygni*, is still well seen as a star of the fifth magnitude, which does not now vary perceptibly. Moreover, *η Carinae* appears as a star of the seventh magnitude, after undergoing great and irregular changes in light during nearly a century.

From the Draper Memorial photographs it has been shown that the spectra of variables of long period are generally either of the third type, Class Md, in which one or more of the hydrogen lines, $H\delta$, $H\gamma$, and $H\beta$, but not $H\epsilon$, are bright, or of the fourth type, Class N. The spectra of the bright novæ are very complex, but when faint even at maximum only a few bright lines are visible. These consist of the hydrogen lines $H\epsilon$, $H\delta$, $H\gamma$, and $H\beta$, and one or more bright lines between λ4600 and 4700, which appear to coincide with the characteristic bands of spectra of the fifth type. *Nova Centauri*, however, had a wholly different spectrum.

In Circular No. 76, Mrs. Fleming pointed out that the spectrum of the star *174406, RS Ophiuchi*, on July 15, 1898, was of the third type in which the hydrogen lines $H\zeta$, $H\epsilon$, $H\delta$, $H\gamma$, and $H\beta$ were bright, and also two lines which appear to coincide with the bright bands 4656 and 4691, in *γ Velorum*. As these bands have a width of several units and are sometimes brighter on one edge than on the other, it is impossible to give their exact wave-lengths. This spectrum, therefore, closely resembles that of *Nova Sagittarii* and *Nova Geminorum*. A photograph taken on the preceding day, July 14, confirms the presence of these lines, while a photograph taken on August 28, 1894, showed that at that time the spectrum was of Class K, with no evidence of bright lines. Mrs. Fleming's record in 1899, after examining the first of these was "Nova?"

TABLE I

ANNUAL RESULTS

Year	No.	Mean	A. D.	Year	No.	Mean	A. D.
1888	1	10.86	..	1898	11	.....	.
1890	2	10.88	0.02	1899	14	10.56	0.26
1891	2	10.78	.02	1900	24	9.67	.32
1892	4	10.65	.11	1901	34	9.82	.23
1893	7	10.26	.10	1902	41	9.97	.18
1894	6	10.46	.28	1903	26	10.28	.20
1895	6	10.36	.07	1904	51	10.24	.18
1896	9	10.21	.18	1905	4	9.78	.26
1897	11	10.50	.23	....	..	.....	...

Miss Cannon, from an examination of the light-curve, called attention to the remarkable increase in the light of this star which took place in 1898. The star has been photographed at the Observatory each year since 1888, except in 1889. The year, number of photographs, mean magnitude, and average deviation of the separate results are given in Table I. The individual results in 1898 are given in Table II.

TABLE II

RESULTS FOR 1898

Date	Mag.	Date	Mag.
April 2	10.70	August 15	9.27
May 27	10.76	August 20	9.32
May 31	10.81	September 7	10.00
June 30	7.69	September 29	10.28
July 14	8.26	October 8	10.81
July 15	8.22		....

It will be seen from these tables that the star appears to have had the magnitude 10.9, before 1891, then increasing gradually about half a magnitude to 10.4, and retaining this brightness during 1893 to 1897. In 1898 it was at first faint, magnitude 10.8, until May 31. A month later, on June 30, it was more than three magnitudes brighter, or 7.7 and decreased regularly about a magnitude a month until October 8, when it was again magnitude 10.8. The following year, 1899, it remained faint, 10.6, but in 1900 it attained the magnitude 9.3 in April, diminishing to 10.0 in September. This change accounts for the large average deviation in the fourth column. Since then the variations have been slight. An examination of several good chart plates shows only one star in this position.

Nearly all of the objects mentioned above are shown on the Harvard Map of the Sky. *RS Ophiuchi* appears on Plate 31, [118, 58]; *T Coronae*, on Plate 18, [113, 59]; *Nova Persei*, No. 2, on Plate 12, [131, 185]; *P Cygni*, on Plate 20, [72, 149]; *η Carinae*, on Plate 50, [153, 64]; *γ Velorum*, on Plate 49, [155, 168]; and *Nova Geminorum*, on Plate 13, [39, 107].

Both the spectrum and the light-curves therefore indicate that this object should be regarded as a Nova, rather than a variable star, and its proper designation will be *Nova Ophiuchi*, No. 3, the new stars of 1604 and 1848 having also appeared in the same constellation.

EDWARD C. PICKERING.

MAY 15, 1905.